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مجلة الشمال

للعلوم الأساسية والتطبيقية

دورية علمية محكمة

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مجلة الشمال للعلوم الأساسية والتطبيقية (JNBAS)

هيئــة التحـــرير

بسم اللہ الرحمن الرحیم

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المملكة العربية السعودية

مجلة الشمال
للعلوم الأساسية والتطبيقية

(JNBAS)

دورية علمية محكمة

تصدر عن

مركز النشر العلمي والتأليف والترجمة

جامعة الحدود الشمالية

المجلد الثامن ـ العدد الأول

مايو 2023م ـ شوّال 1444هـ

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مجلة الشمال للعلوم الأساسية والتطبيقية (JNBAS)

التعريف بالمجلة

تعنى المجلة بنشر البحوث والدراسات العلمية الأصيلة في مجال العلوم الأساسية والتطبيقية، باللغتين العربية والإنجليزية، كما تهتم بنشر جميع ما له علاقة بعرض الكتب ومراجعتها أو ترجمتها، وملخصات الرسائل العلمية، وتقارير المؤتمرات والندوات العلمية، وتصدر مرتين في السنة (مايو ـ نوفمبر).

الرؤية

الريادة في نشر البحوث العلمية المحكمة، وتصنيف المجلة ضمن أشهر الدوريات العلمية العالمية.

الرسالة

نشر البحوث العلمية المحكمة في مجال العلوم الأساسية والتطبيقية وفق معايير عالمية متميزة.

أهداف المجلة

1) أن تكون المجلة مرجعًا علميًا للباحثين في العلوم الأساسية والتطبيقية.
2) تلبية حاجة الباحثين إلى نشر بحوثهم العلمية، وإبراز مجهوداتهم البحثية على المستويات المحلية والإقليمية والعالمية.
3) المشاركة في بناء مجتمع المعرفة بنشر البحوث الرصينة التي تؤدي إلى تنمية المجتمع.
4) تغطية أعمال المؤتمرات العلمية المحكمة.

شروط قبول البحث

1) الأصالة والابتكار وسلامة المنهج والاتجاه.
2) الالتزام بالمناهج والأدوات والوسائل العلمية المتبعة في مجاله.
3) الدقة في التوثيق والمصادر والمراجع والتخريج.
4) سلامة اللغة.
5) أن يكون البحث غير منشور أو مقدم للنشر في أي مكان آخر.
6) أن يكون البحث المستل من الرسائل العلمية غير منشور أو مقدم للنشر، وأن يشير الباحث إلى أنه مستلٌ.

للمراسلة

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شروط النشر

أولاً: ضوابط النص المقدم للنشر

1) ألا تزيد صفحاته عن (35) صفحة من القطع العادي (A4).
2) أن يحتوي على عنوان البحث وملخصه باللغتين العربية والإنجليزية في صفحةٍ واحدة، بحيث لا يزيد عن (250) كلمة للملخص، وأن يتضمن البحث كلمات مفتاحيةٍ دالةٍ على التخصص الدقيق للبحث باللغتين، بحيث لا يتجاوز عددها (6) كلمات، توضع بعد نهاية كل ملخص.
3) أن يذكر اسم المؤلف وجهة عمله بعد عنوان البحث مباشرة باللغتين العربية والإنجليزية.
4) أن تقدم البحوث العربية مطبوعة بخط (Simplified Arabic)، بحجم (14) للنصوص في المتن، وبالخط نفسه بحجم (12) للهوامش.
5) أن تقدم البحوث الإنجليزية مطبوعة بخط (Times New Roman) بحجم (12) للنصوص في المتن، وبالخط نفسه بحجم (9) للهوامش.
6) كتابة البحث على وجه واحد من الصفحة، مع ترك مسافة سطر واحد بين السطور، وتكون الحواشي 2.5 سم على الجوانب الأربعة للصفحة، بما يعادل 1.00 إنش (بوصة).
7) التزام الترتيب الموضوعي الآتي:

المقدمــة: تكون دالة على موضوع البحث، والهدف منه، ومنسجمة مع ما يَردُ في البحث من معلومات وأفكار وحقائق علمية، كما تشير باختصار إلى مشكلة البحث، وأهمية الدراسات السابقة.

العرض: يتضمن التفاصيل الأساسية لمنهجية البحث، والأدوات والطرق التي تخدم الهدف، وترتب المعلومات حسب أولويتها.

النتائج والمناقشة: يجب أن تكون واضحة موجزة، مع بيان دلالاتها دون تكرار.

الخاتمة: تتضمن تلخيصًا موجزًا للموضوع، وما توصل إليه الباحث من نتائج، مع ذكر التوصيات والمقترحات.

8) أن تدرج الرسوم البيانية والأشكال التوضيحية في النص، وترقم ترقيماً متسلسلاً، وتكتب أسماؤها والملاحظات التوضيحية أسفلها.
9) أن تدرج الجداول في النص، وترقم ترقيماً متسلسلاً، وتكتب أسماؤها أعلاها، وأما الملاحظات التوضيحية فتكتب أسفل الجدول.
10) ألا توضع الهوامش أسفل الصفحة إلا عند الضرورة فقط، ويشار إليها برقم أو نجمة، ويكون الخط فيها بحجم (12) للعربي و (9) للإنجليزي.
11) لا تنشر المجلة أدوات البحث والقياس، وتقوم بحذفها عند طباعة المجلة.
12) أن يُراعى في منهج توثيق المصادر والمراجع داخل النص نظام (APA)، وهو نظام يعتمد ذكر الاسم والتاريخ (name/year) داخل المتن، ولا يقبل نظام ترقيم المراجع داخل النص مع وضع الحاشية أسفل الصفحة، وتوضع المصادر والمراجع داخل المتن بين قوسين حسب الأمثلة الآتية: يذكر اسم عائلة المؤلف متبوعا بفاصلة، فسنة النشر، مثلا: (مجاهد، 1988م). وفي حالة الاقتباس المباشر يضاف رقم الصفحة مباشرة بعد تاريخ النشر مثلا: (خيري، 1985م، ص:33). أما إذا كان للمصدر مؤلفان فيذكران مع اتباع الخطوات السابقة مثلا: (الفالح وعياش، 1424هـ). وفي حالة وجود أكثر من مؤلفين فتذكر أسماء عوائلهم أول مرة، مثلا: (مجاهد والعودات والشيخ، 1408هـ)، وإذا تكرر الاقتباس من المصدر نفسه فيشار إلى اسم عائلة المؤلف الأول فقط، ويكتب بعده وآخرون مثل: (مجاهد وآخرون، 1408هـ)، على أن تكتب معلومات النشر كاملة في قائمة المصادر والمراجع.
13) تخرج الأحاديث والآثار على النحو الآتي:
(صحيح البخاري، ج:1، ص: 5، رقم الحديث 511).
14) توضع قائمة المصادر والمراجع في نهاية البحث مرتبة ترتيباً هجائياً حسب اسم العائلة، ووفق نظام جمعية علم النفس الأمريكية (APA) الإصدار السادس، وبحجم (12) للعربي و(9) للإنجليزي، وترتب البيانات الببليوغرافية على النحو الآتي:

- **الاقتباس من كتاب لمؤلف واحد:**

الخوجلي، أحمد. (2004م). ***مبادئ فيزياء الجوامد***. الخرطوم، السودان: عزة للنشر والتوزيع.

- **الاقتباس من كتاب لأكثر من مؤلف:**

نيوباي، تيموثي؛ ستيبتش، دونالد؛ راس، جيمس. (1434هـ/2013م). ***التقنية التعليمية للتعليم والتعلم***. الرياض، المملكة العربية السعودية: دار جامعة الملك سعود للنشر.

- **الاقتباس من دورية:**

النافع، عبداللطيف حمود. (1427هـ). أثر قيادة السيارات خارج الطرق المعبدة في الغطاء النباتي بالمتنزهات البرية: دارسة في حماية البيئة، في وسط المملكة العربية السعودية. ***المجلة السعودية في علوم الحياة***، *14*(1)، 53-72.

- **الاقتباس من رسالة ماجستير أو دكتوراه:**

القاضي، إيمان عبدالله. (1429هـ). ***النباتات الطبيعية للبيئة الساحلية بين رأسي تنورة والملوح بالمنطقة الشرقية: دراسة في الجغرافيا النباتية وحماية البيئة***. رسالة دكتوراه غير منشورة، كلية الآداب للبنات، الدمام، المملكة العربية السعودية: جامعة الملك فيصل.

- **الاقتباس من الشبكة العنكبوتية (الإنترنت):**

- الاقتباس من كتاب:

المزروعي، م.ر. و المدني، م.ف. (2010م). ***تقييم الأداء في مؤسسات التعليم العالي***. المعرِّف الرقمي (DOI:10.xxxx/xxxx-xxxxxxxx-x)، أو بروتوكول نقل النصوص التشعبي (http://www...)، أو الرقم المعياري الدولي للكتاب (ISBN : 000-0- 00 - 000000-0)

– الاقتباس من مقالة في دورية:

المدني، م.ف. (2014). مفهوم الحوار في تقريب وجهات النظر. ***المجلة البريطانية لتكنولوجيا التعليم***، *11*(6)، 225-260. المعرِّف الرقمي (DOI:10.xxxx/xxxx-xxxxxxxx-x) أو بروتوكول نقل النصوص التشعبي (http://onlinelibrary.wiley.com/journal/10.1111)، أو الرقم المعياري التسلسلي الدولي للمجلة (ISSN: 1467 - 8535).

15) يلتزم الباحث بترجمة (أو رومنة) أسماء المصادر والمراجع العربية إلى اللغة الإنجليزية في قائمة المصادر والمراجع. وعلى سبيل المثال:

الجبر، سليمان. (1991م). تقويم طرق تدريس الجغرافيا ومدى اختلافها باختلاف خبرات المدرسين وجنسياتهم وتخصصاتهم في المرحلة المتوسطة بالمملكة العربية السعودية. **مجلة جامعة الملك سعود- العلوم التربوية**، *3*(1)، 143-170.

Al-Gabr, S. (1991). The Evaluation of Geography Instruction and the Variety of its Teaching Concerning the Experience, Nationality, and the Field of Study in Intermediate Schools in Saudi Arabia *(in Arabic). Journal of King Saud University- Educational Sciences, 3*(1), 143-170.

16) تستخدم الأرقام العربية الأصلية (0، 1، 2، 3، ...) في البحث.

17) تؤول جميع حقوق النشر للمجلة في حال إرسال البحث للتحكيم وقبوله للنشر.

ثانياً: الأشياء المطلوب تسليمها

1) نسخة إلكترونية من البحث بصيغتي (WORD) و (PDF)، وترسلان على البريد الإلكتروني الآتي:

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2) السيرة الذاتية للباحث، متضمنة اسمه باللغتين العربية والإنجليزية، وعنوان البريد الإلكتروني الحالي، ورتبته العلمية.

3) تعبئة النماذج الآتية:

أ - نموذج طلب نشر بحث في المجلة.

ب - نموذج تعهد بأن البحث غير منشور أو مقدم للنشر في مكان آخر.

ثالثاً: تنبيهات عامة

1) أصول البحث التي تصل إلى المجلة لا تردّ سواء أَنُشِرَتْ أم لم تنشر.

2) الآراء الواردة في البحوث المنشورة تعبر عن وجهة نظر أصحابها.

مجلة الشمال للعلوم الأساسية والتطبيقية (JNBAS)

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المجلد الثامن - العدد الأول مايو 2023م - شوَّال 1444هـ

المحتويات

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dispersion of the photo-catalyst in the experiments.

4. CONCLUSION

The application of photo-catalytic self-cleaning concrete to remove organic impurities from water was the main concern of this work. Photo-catalyst nanoparticles was used in order to stabilize the catalyst and avoid electron-hole recombination events in the semiconductor. The produced photo-catalyst is then applied to the surface of the blocks of concrete blocks. The experimental conduct of nanoparticle synthesis was optimized using a response surface methodology (RSM). The effect of stirring speed, the temperature and the concentration of zinc acetate on the nanoparticles diameter were studied. A Box-Behnken (BB) design with three factors and three center points was used. For each synthesis experiment, the average of particles diameter is estimated from the (XRD) characterization and Scherer's equation. All research parameters (temperature, stirring duration, and zinc acetate concentration) are significant, as shown by the Pareto chart of the standardized effects. Moreover, relationships between temperature and stirring time and concentration and stirring time are significant factors. The size of the synthesized particles is most significantly influenced by temperature. In fact, when the temperature increases, the precursor (zinc acetate) becomes more soluble and the emergence of nanoparticles occurs faster. It should be highlighted that the most effective zone for reducing particle size corresponds to the green light zone (15nm-dp-16nm). The variation in stirring time as a function of concentration was found to behave similarly.

For the optimal particle size value (13.897nm), the standard error of the fit (SE) is very low (0.137). Consequently, the regression model used is reliable for the prediction of the particle size as a function of the operating conditions.

The degradation results of the pollutant model (CV) are carried out for different sizes of synthesized particles (14.2 nm, 16.8 nm, 19 nm) and an average particle size of commercial ZnO (50 nm). The temporal evolution of the conversion rate for the particles size of 50 nm shows that the maximum conversion rate is reached after 40 min. The smaller the size, the greater the reaction rate becomes. The results show that decreasing the particle size from 50 nm to 14.2 nm improves the maximum conversion rate by 33% and an acceleration of the reaction rate by 28%. Therefore, decreasing the particle size is an effective way to enhance the conversion rate as well as the rate of reaction, thus allowing for shorter reaction times with higher yields.

The concentration profile at the surface of the concrete paving block is estimated, by simulation, as a function of time for the minimum particle size (14.2 nm). The average concentration at the surface for t=0min is equal to 10mg/L. Then the concentration decreases gradually to reach the values of 4.30mg/L, 1.80 mg/L, and 0.85 mg/L for the respective times 5min, 10min and 23min. The maximum conversion rate achieved is 91.5%. The uniformity of the concentration at the surface of concrete paving block can be explained by the step that controls the photo-catalytic degradation process: the reaction rate is faster than the transport of the pollutant on the catalyst and therefore the pollutant degrades rapidly compared to its residence time crossing the surface.

Finally, to validate the numerical model simulating the self-cleaning concrete paving block, a comparison of the experimental and modeled reaction rates was established. For the diameter of 50 nm, the simulation results fit the experiments correctly. For smaller particle sizes, simulation results show slightly higher conversion rates than experiments (2 to 3%). This difference can be explained by the perfect homogeneity of the dispersion of the photo-catalyst, on the concrete paving block, in simulations against slight defiance in the real dispersion of the photo-catalyst in the experiments.

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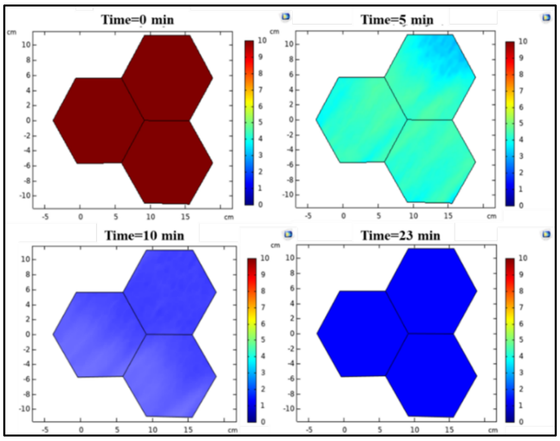


Figure 11: Concentration profiles at the surface of the concrete paving block.

Figure 11 shows that the average concentration at the surface for t=0min is equal to 10mg/L. Then the concentration decreases gradually to reach the values of 4.30mg/L, 1.80 mg/L, and 0.85 mg/L for the respective times 5min, 10min and 23min. The maximum conversion rate achieved is 91.5%.

The uniformity of the concentration at the surface can be explained by the step that controls the photo-catalytic degradation process: the reaction rate is faster than the transport of the pollutant on the catalyst and therefore the pollutant degrades rapidly compared to its residence time crossing the surface.

Finally, to validate the numerical model simulating the self-cleaning concrete paving block, a comparison of the experimental and modeled reaction rates was established as represented by figure 12.

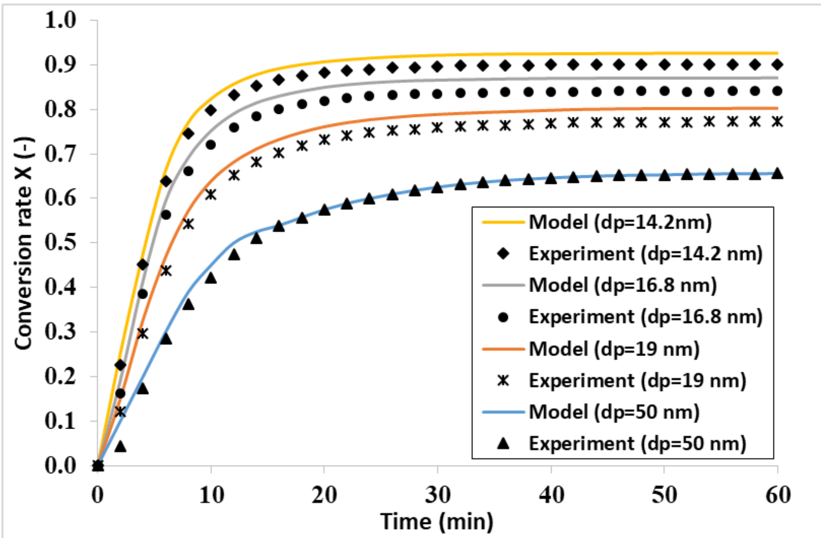


Figure 12: Concentration profiles at the surface of the concrete paving block.

For the diameter of 50 nm, the simulation results fit the experiments correctly. For smaller particle sizes, simulation results show slightly higher conversion rates than experiments (2 to 3%). This difference can be explained by the perfect homogeneity of the dispersion of the photo-catalyst, on the concrete paving block, in simulations against slight defiance in the real particles will have a greater chance of coming into contact with each other.

The second approach in this section concerns a numerical simulation by COMSOL Multiphysics©. This simulation is based on the finite element method allowing a numerical resolution of the transport and diffusion equations of the pollutant (CV) (equation 5), and of the catalytic degradation reaction at the surface of concrete paving blocks.

$$\frac{\partial C}{\partial t} + \nabla . J + u . \nabla C = R \; and \; J = -D \nabla C \qquad (5)$$

With:

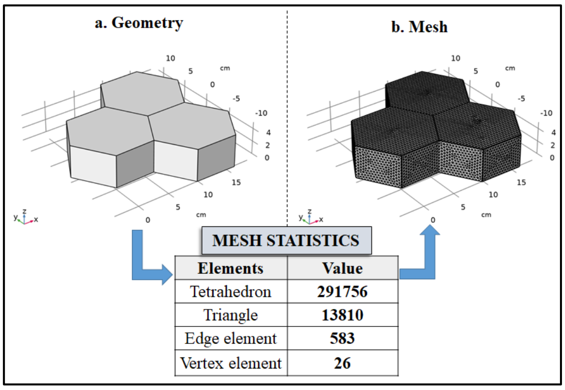
C the pollutant concentration (CV) at the concrete paving block surface,

U: the flow velocity of the pollutant on the concrete paving block surface,

A: the speed of the reaction on the surface of concrete paving block,

D: the coefficient of the pollutant diffusion (CV).

To solve the differential equation (Eq5) by finite element method, a temporal and spatial discretization was performed. The geometry was designed with the real dimensions of the concrete paving block (figure 10.a). Then a parametric study of the mesh of the geometry was developed and allowed to choose the shape and the size of elements represented by figure 10.b. The numerical resolution with a total number of elements of 306175, ensured the simulation with reasonable computation time (30min) and accuracy.



Elements	Value
Tetrahedron	291756
Triangle	13810
Edge element	583
Vertex element	26

Figure 10: Geometry and mesh of simulated concrete paving block.

The concentration profile at the surface of the concrete paving block is estimated, by simulation, as a function of time for the minimum particle size (14.2 nm) as represented by figure 11.

Figure 8: Maximum conversion rate (X) reached for each chosen particle size.

Figure 8 shows that the maximum conversion rate reached increases with the reduction in the size of the photo-catalyst particles. Indeed, the reduction in the size of the particles increases the specific surface of the concrete paving block: If we compare the shape of the photo-catalyst (ZnO) to a spherical particle, the relation of the specific surface (S_{sp}) according to the size of the particle (r) is given by the equation 4 (Hariharan, 2006):

$$S_{sp} = \frac{3}{\rho r} \quad (4)$$

In the other hand, the effect of particle size on the UV radiation penetration of photo-catalyst is a significant factor to consider. Studies have found that smaller particles are more effective, allowing more radiation penetration and therefore allowing for better catalytic performance (Chen et al., 2018; Corma, Martınez, & Martınez-Soria, 2001; Lv et al., 2023; W. Wang et al., 2023). This is due to the larger surface area in contact with the UV radiation, which increases the reaction rate, resulting in improved photo-catalytic performance. The particle size of a photo-catalyst is therefore an important factor in optimizing UV radiation penetration and maximizing its catalytic efficiency(Roy, Mondal, & Mitra, 2023; Y. Wang et al., 2022).

In addition, the rate of photo-catalytic degradation is analyzed by the temporal evolution of the conversion rate of (CV) as shown in Figure 9.

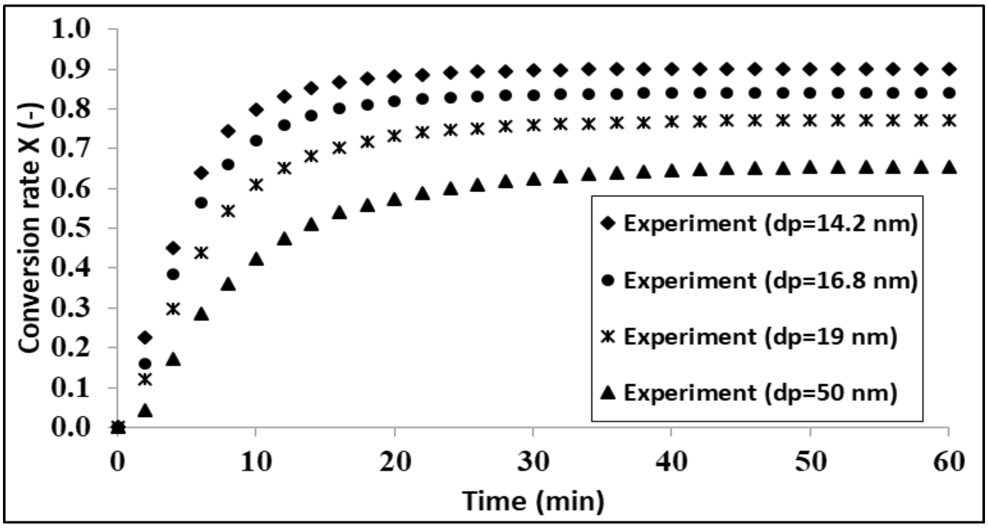


Figure 9: Temporal evolution of the conversion rate of (CV)

Figure 9 shows that in addition to its effect on overall conversion rate, particle size also affects the reaction rate. Indeed, the temporal evolution of the rate of conversion rate for the particles size of 50 nm shows that the maximum conversion rate is reached after 40 min. The smaller the size, the greater the reaction rate becomes. The conversion times of (CV) are 32 min, 26 min and 23 min for the particle sizes 19nm, 16.8nm and 14.2nm respectively. The results show that decreasing the particle size from 50 nm to 14.2 nm improves the maximum conversion rate by 33% and an acceleration of the reaction rate by 28%.

Therefore, decreasing the particle size is an effective way to enhance the conversion rate as well as the rate of reaction, thus allowing for shorter reaction times with higher yields. This is because decreasing the particle size increases the surface area of the reactants, resulting in more collisions and better mass transfer between phases. This can be especially beneficial when dealing with low solubility reactants since smaller

Table 4: Optimization results.

Solution	[Zn-(CH3COO)2,2H2O]	Temperature	Stirring time	dp Fit
1	0.327273	80	5	13.8967

The particle size fuction of (temperature (T), stirring time (S.t), and zinc acetate concentration (Z.A)) is given by the regression model equation 3.

$$dp = 10.56 + 47.78\,[Z.A] + 0.15\,T + 2.55 S.t - 0.72\,[Z.A]*T - 8.89\,[Z.A]*S.t - 0.04\,T*S.t + 0.11\,[Z.A]*T*S.t \quad (3)$$

The results of the prediction of the minimum particle size value using the regression model (equation 3) is illustrated in Table 5.

Table 5: Confidence and prediction intervals of the optimum result.

Response	Fit	SE Fit	95% CI	95% PI
dp	13.897	0.137	(13.545, 14.248)	(13.381, 14.412)

For the optimal particle size value (13.897nm), the standard error of the fit (SE) is very low (0.137). Consequently, the regression model used is reliable for the prediction of the particle size as a function of the operating conditions. On the other hand, with a confidence level (CL) of 95%, the confidence interval contains the mean of the population of the operating conditions considered. Likewise, the prediction interval indicates that with a 95% of chance one response will be contained in the interval of the chosen operating conditions (variables)(Greenland et al., 2016). For the two confidence indicators, the intervals are small and therefore the prediction is reliable.

3.2 Photo-catalytic tests of concrete paving blocks

The synthesized nanoparticles are placed on the surface of the concrete paving block. Five deposition steps are carried out by drying the blocks each time at 60°C for 2 hours. Then a photo-catalytic test is carried out to evaluate the self-cleaning efficiency of concrete paving block using a model organic pollutant (Crystal viloet). The experimental photo-catalytic protocol is described in section 2.3. The degradation results of the pollutant model (CV) are carried out for different sizes of synthesized particles (14.2 nm, 16.8 nm, 19 nm) and an average particle size of commercial ZnO (50 nm). The maximum conversion rate (X) reached for each chosen particle size is shown in Figure 8.

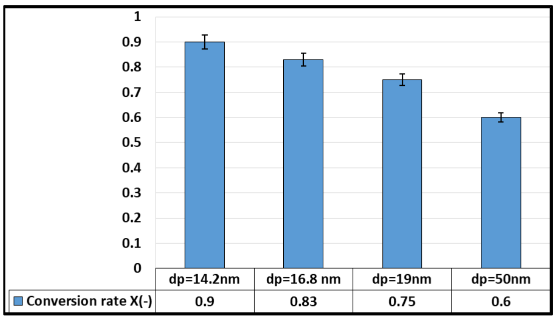


Figure 6: Interaction effects plots on the nanoparticles size.

Figure 6.a and 6.c show the presence of a weak [Zn-$(CH_3COO)_2$,$2H_2O$]*Temperature interaction. This interpretation is consistent with the Pareto chart. Based on the variation of the particle size as a function of the concentration of zinc acetate for different temperatures, we can deduce that the increase in temperature favors the reduction in the size of the particles without however interacting clearly with the Zinc acetate concentration. Similarly, the interaction $(CH_3COO)_2$,$2H_2O$]*stirring time (figures 6.b and 6.e) is weak but more important than the previous interaction. Indeed Pareto chart shows that this interaction is slightly higher than the starting point of significance.

On the other hand, we notice a strong interaction between the temperature and the stirring time represented by figure 6.d and 6.f. the particle size decreases with increasing temperature and stirring speed of 2 and 5h. However, it is noted that the particle size is kept constant in the temperature range between 65 and 80 and for a stirring speed of 3.5h. In this temperature range the effects are compensated.

To better represent the impact of the interactions on the final size of the nanoparticles, the analysis of the contours of the factors is represented by figure 7.

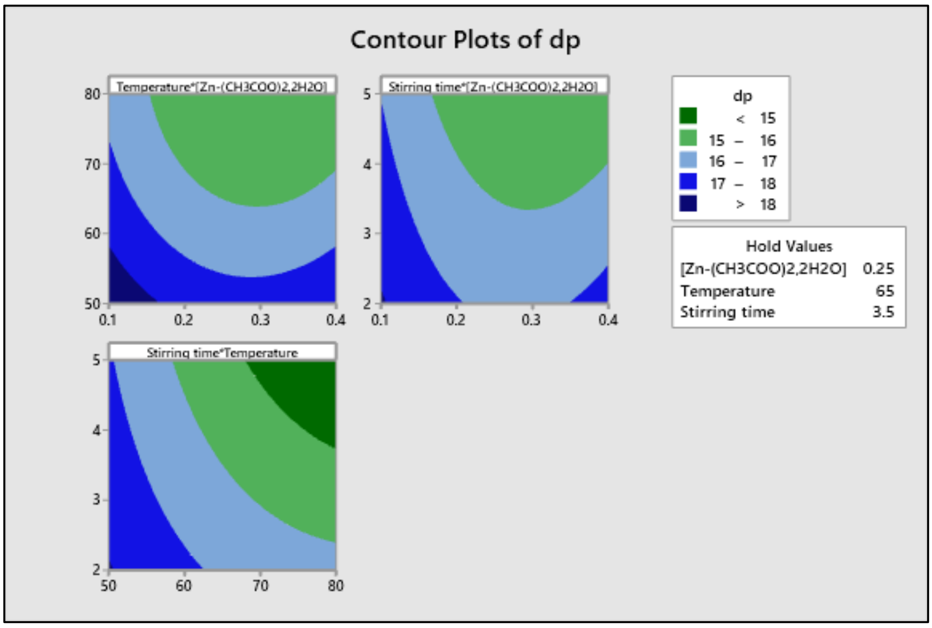


Figure 7: Contour plots of interaction effects on the nanoparticles size.

Figure 7 shows the ranges of concentration, temperature and agitation time allowing to minimize the size of the particles. It is noted that green light zone (15nm<dp<16nm) corresponds to the most favorable zone for minimizing the size of the particles. For cost and experiment time, an experimental point on the border of this area may be chosen. The same observation was concluded for the variation of the stirring time as a function of the concentration.

On the other hand, the areas in blue are experimental conditions to be avoided. For the variation of stirring time as a function of temperature, a new dark green zone appears and gives a particle size of less than 15 nm for large values of temperature and stirring time.

Finally, an optimization of the operating conditions aimed to minimizing the size of the nanoparticles was performed. The optimization results are grouped in the table 4.

a separate analysis of the evolution of the response (size of the particles) according to each factor was carried out. The results are represented by the figure 5.

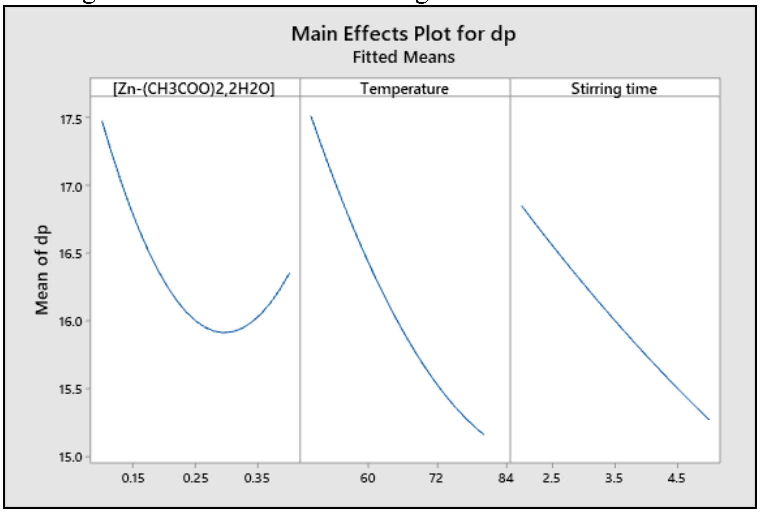
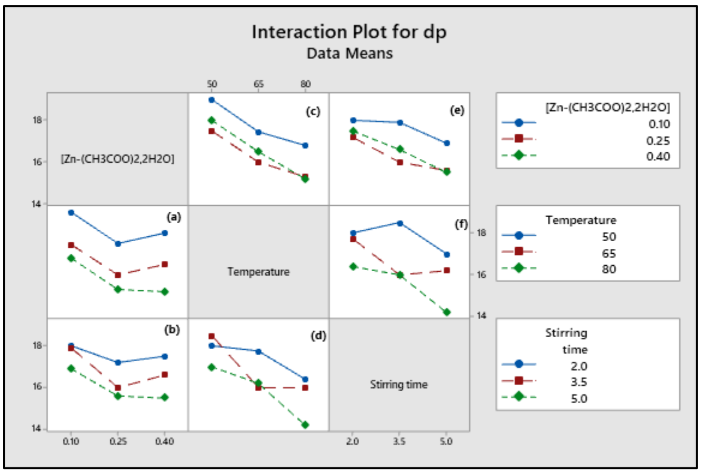


Figure 5: Main effects plots on the nanoparticles size.

Figure 5 shows that increasing the concentration of zinc acetate promotes a reduction in particle size until a limit value of 0.3 mmol/L is reached, which corresponds to a particle size equal to 15.9 nm. Beyond this concentration, the nanoparticle size begins to increase. Consequently, the concentration of zinc acetate is not beneficial in reducing the size of nanoparticles for a value greater than 0.3 mmol/L. The increase in temperature and stirring time promotes the reduction in particle size throughout the experimental variation range. They follow a linear variation trend.

On the other hand, the analysis of the interactions represented by figure 6, makes it possible to understand the impact of the simultaneous variation of the factors. To analyze the effects of interactions the following points have to be considered.

- The parallel lines mean the absence of interaction. The farther the lines are from being parallel, the stronger the interactions.
- As an example, the intersection between column 1 and row 2 indicates the interaction between [Zn-$(CH_3COO)_2$, $2H_2O$] and temperature ([Zn-$(CH_3COO)_2$,$2H_2O$]*Temperature).



14	**15**	**0.25**	**65**	**3.5**	**16**

A comparison of the term's p-value to the significance level can show whether there is a statistically significant relationship between the response and each factor in the model. The null hypothesis is that there is no association between the term and the response because the term's coefficient is equal to zero. The significance value (alpha) in this study is set at 0.05. The results of the experimental design regression and Pareto chart are shown in figure 4.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	16.0000	0.0847	189.00	0.000	
[Zn-(CH3COO)2,2H2O]	-0.5625	0.0518	-10.85	0.000	1.00
Temperature	-1.1750	0.0518	-22.67	0.000	1.00
Stirring time	-0.7875	0.0518	-15.19	0.000	1.00
[Zn-(CH3COO)2,2H2O]*[Zn-(CH3COO)2,2H2O]	0.9125	0.0763	11.96	0.000	1.01
Temperature*Temperature	0.3375	0.0763	4.42	0.007	1.01
Stirring time*Stirring time	0.0625	0.0763	0.82	0.450	1.01
[Zn-(CH3COO)2,2H2O]*Temperature	-0.1500	0.0733	-2.05	0.096	1.00
[Zn-(CH3COO)2,2H2O]*Stirring time	-0.2250	0.0733	-3.07	0.028	1.00
Temperature*Stirring time	-0.3000	0.0733	-4.09	0.009	1.00

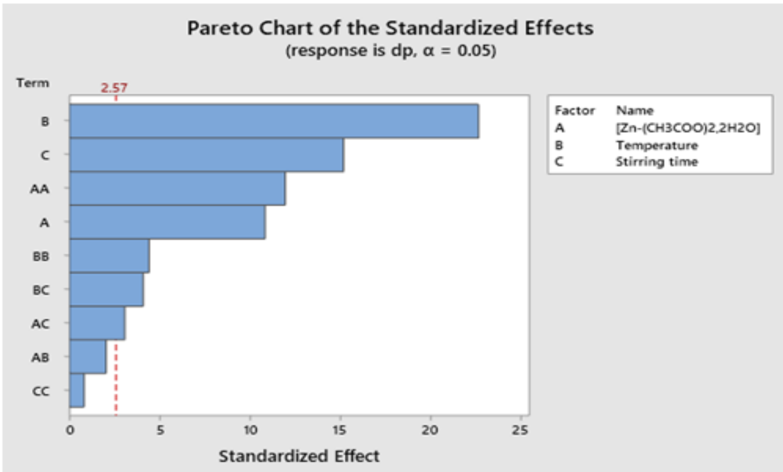
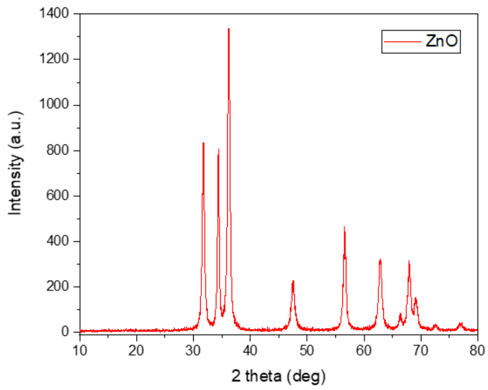


Figure 4: Experimental design regression and Pareto chart.

The Pareto chart of the standardized effects shows that all study factors (temperature, stirring time, and zinc acetate concentration) are significant. Moreover temperature-stirring time and concentration-stirring time interactions are also significant as factors influencing nanoparticle size.
The temperature is the most significant factor on the size of the synthesized particles. Indeed, the increase in temperature promotes the solubility of the precursor (zinc acetate) and accelerates the appearance of nanoparticles. Other research works have mentioned that the addition of NaOH also promotes the dissolution of the initially poorly soluble zinc acetate in the water-ethanol mixture.
For a fixed added quantity of NaoH, temperature is the most significant factor and therefore controls the process of nanoparticle synthesis.
However, it should be noted that Pareto chart makes it possible to judge the significance of the studied factors without showing if the variation of each factor will be beneficial to the minimization of the sizes of synthesized nanoparticles. For this,

in the 7th experiment is represented by the figure 3.



2θ (degree)	FWHM(degree)
31.684	0.49821
34.34119	0.36237
36.17478	0.49851
47.46389	0.4717
56.52958	0.5429
62.78254	0.53644
66.35745	0.8252
67.87667	0.60875
69.00625	0.67842
72.4913	0.3408
76.89291	0.46543

Figure 3: X-ray diffraction (XRD) characterization of ZnO nanoparticles in the 7th experience.

X-ray diffraction (XRD) characterization of ZnO allow to deduce the values of FWHM and then to calculate the average diameter of ZnO particles. It should be noted that the excessive reduction in the size of the particles can lead to the dissolution of the nanoparticles in the synthesis solution and complicates the solid-liquid separation.The average value of the diameter of the nanoparticles, in 7th experience, is equal to 18 nm. The same experimental protocol was applied to the other conditions as shown in Table 3.

Table 3: Results of ZnO nanoparticles diameter.

StdOrder	RunOrder	[Zn-(CH3COO)$_2$,2H$_2$O] (mmol/L)	Temperature (°C)	Stirring time (hr)	dp (nm)
13	1	0.25	65	3.5	16
7	2	0.1	65	5	16.9
11	3	0.25	50	5	17
9	4	0.25	50	2	18
6	5	0.4	65	2	17.5
8	6	0.4	65	5	15.5
2	7	0.4	50	3.5	18
5	8	0.1	65	2	18
10	9	0.25	80	2	16.4
1	10	0.1	50	3.5	19
15	11	0.25	65	3.5	16
12	12	0.25	80	5	14.2
3	13	0.1	80	3.5	16.8
4	14	0.4	80	3.5	15.2

Broadening of the peak), θ is the corresponding diffraction angle, and K the shape constant.

2.3 Photo-catalytic activity tests

The photo-catalytic degradation of the pollutant -Crystal Violet (CV)-, is carried out on the surface of the concrete paving block. The concrete paving block is placed in the reactor containing an initial concentration of 10 $mg.L^{-1}$. The first step consists in the adsorption of the pollutant on the surface of the block for 30 min in the dark. Then a UV lamp is used to irradiate the surface of the block containing the photo-catalyst and the concentration is measured at the outlet of the reactor every 2 min. The concentration is determined using a Thermo Scientific Evolution 300 UV-Visible spectrophotometer.Finally, the degradation efficiency (X) of the nanoparticles was estimated by the following equation (2):

$$X = \frac{C_0 - C_f}{C_0} \qquad (2)$$

Where C_0 and C_f are the initial and the final concentration of CV.

The experimental device used is represented by the figure2.

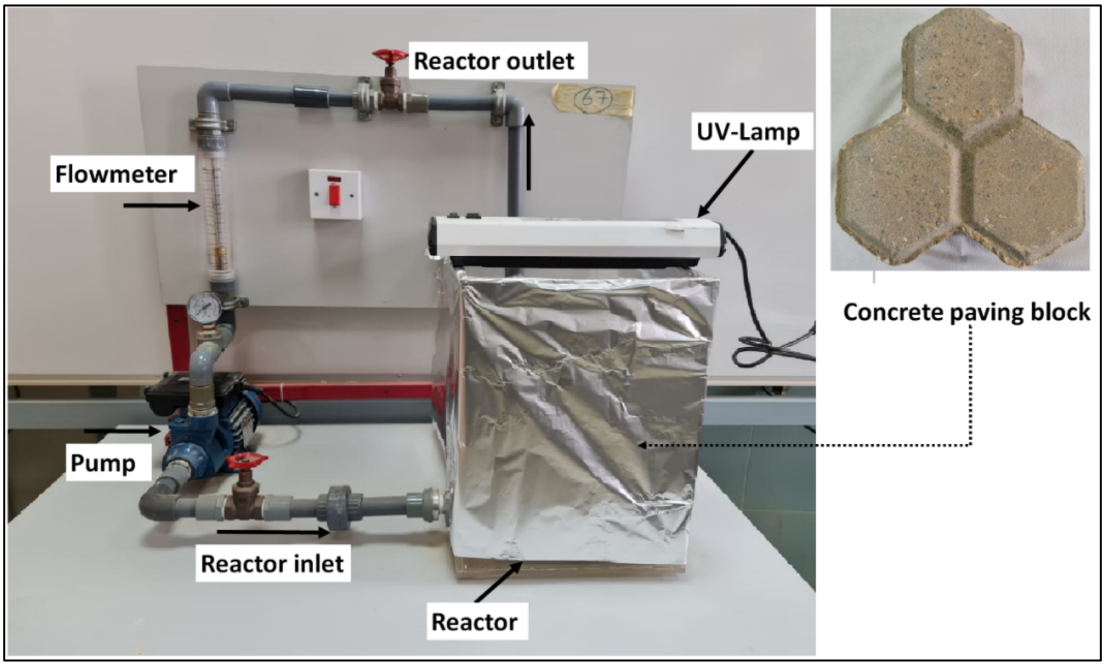


Figure 2: Experimental device of photo-catalytic degradation of (CV) on the surface of the concrete paving block

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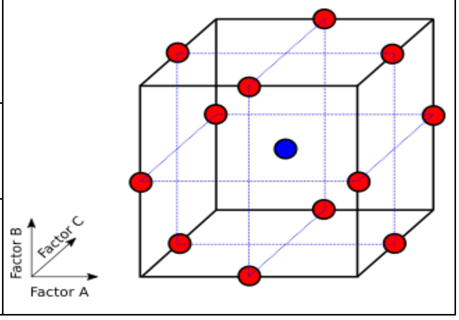
3. RESULTS AND DISCUSSION

3.1 Results of experimental design

The experimental methodology proposed later (table 2) was applied. The nanoparticle synthesis experiments were performed in the order specified by RunOrder (Run order). This order allow to conduct the experiment in random sequence and so to reduce the potential for bias.

For each synthesis experiment, the average particle diameter is estimated from the characterization by X-ray diffraction (XRD) and Scherer's equation (1) as mentioned in section 2.2. By way of illustration, X-ray diffraction (XRD) characterization of the nanoparticles synthesized

Table1: Design Summary- Box-Behnken (BB) Design.

<table>
<tr><th colspan="5">Box-Behnken (BB) design: 3 factors and 3 center points</th></tr>
<tr><th colspan="4">Experimental design</th><th>Graphical representation</th></tr>
<tr><td>Factors</td><td>3</td><td>Replicates</td><td>1</td><td rowspan="3">
</td></tr>
<tr><td>Base runs</td><td>15</td><td>Total runs</td><td>15</td></tr>
<tr><td>Base blocks</td><td>1</td><td>Total blocks</td><td>1</td></tr>
</table>

In this design the factors studied (concentration of zinc acetate, temperature, and stirring speed) are considered as continuous variables and are grouped in table 2:

Table 2: ZnO nanoparticles synthesis factor design.

StdOrder	RunOrder	[Zn-(CH3COO)2,2H2O] (mmol/L)	Temperature (°C)	Stirring time (hr)
13	1	0.25	65	3.5
7	2	0.10	65	5.0
11	3	0.25	50	5.0
9	4	0.25	50	2.0
6	5	0.40	65	2.0
8	6	0.40	65	5.0
2	7	0.40	50	3.5
5	8	0.10	65	2.0
10	9	0.25	80	2.0
1	10	0.10	50	3.5
15	11	0.25	65	3.5
12	12	0.25	80	5.0
3	13	0.10	80	3.5
4	14	0.40	80	3.5
14	15	0.25	65	3.5

2.2 Characterizations of ZnO NPs

The produced nanoparticles structure and crystallinity were examined using X-ray diffraction (XRD) on a D8 Advance Bruker diffractometer with Cu-K radiation (λ = 0.15406 nm) at an accelerating voltage of 40 kV in the 20–80° range. Using Scherer's equation (1), the mean crystallite size (dp) value has been calculated (Hossain, Jahan, & Ahmed, 2023).

$$dp = \frac{K\,\lambda}{\beta\,cos\theta} \quad (1)$$

Where λ is the wavelength (λ = 0.154056 nm), β is the full width at a half-maximum (FWHM) (ie.

molecular orbitals is more suited to describe them than the valence band (BV) and conduction band (BC) of solid semiconductors (Gul et al., 2022; Lvov, Potemkin, & Stremoukhov, 2023).

The main problem in this research concerns the remove of organic pollutants from water using photo-catalytic self-cleaning concrete. The enhancement of the catalyst for photo-catalytic degradation, like natural ZnO, is based on the use of nanoparticles in order to stabilize the catalyst and to avoid electron-hole recombination phenomena in the semiconductor. In this work, an addition of catalyst (ZnO) doped by nanoparticles on the concrete was carried out. The synthesis of nanoparticles passes through several preparation stages such as dissolution, centrifugation and extraction of nanoparticles based on ZnO. Then, concrete blocks are prepared by introducing the synthesized photo-catalyst on its surface. A series of photo-catalytic tests are carried out choosing Crystal Violet (CV) as the typical pollutant. Finally, a modeling of the catalytic degradation is performed using the finite element method.

2. MATERIAL AND METHODS

The preparation of self-cleaning concrete paving block takes place in several stages. The first stage consists of synthesizing the activated nanoparticles. The structure and crystallinity of the prepared nano-powders were analyzed by X-Ray Diffraction (XRD) utilizing D8 Advance Bruker diffractometer (Liu, Liu, Yu, Copeland, & Wang, 2023). The catalyst thus prepared will be deposited on the surface of the concrete paving block. To test the self-cleaning efficiency of the concrete, several photo-catalytic tests were performed.

2.1 Preparation of ZnO nanoparticles

ZnO nanoparticles were prepared using the sol-gel method. Zinc acetate dehydrate Zn-$(CH_3COO)_2,2H_2O$, was dissolved in a mixture of deionized water/ethanol and by adding NaOH under agitation.

Then the solution obtained is placed under centrifugation at 3000 rpm for 5 min and the supernatant is then filtered to recover the particles in suspension in addition to those already decanted by centrifugation. Finally, the synthesized nanoparticles are dried and calcined at 500°C.On the other hand, a response surface methodology was used to optimize the experimental conduct of nanoparticle synthesis. The effect of stirring speed, the temperature and the concentration of zinc acetate on the nanoparticles diameter were studied. The nanoparticle synthesis steps are described in the figure1:

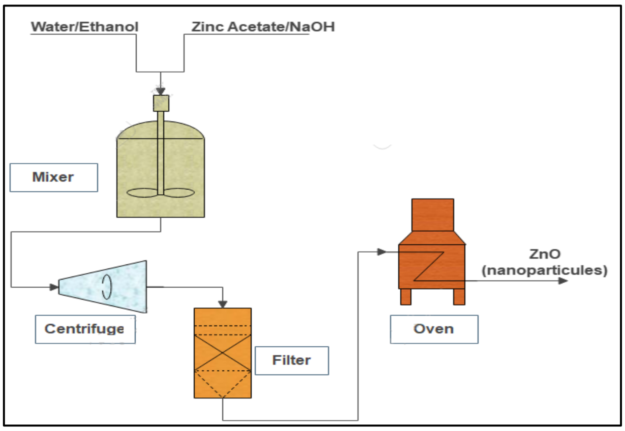


Figure 1: ZnO nanoparticle synthesis steps.

The tables 1 groups the experimental conditions for the synthesis of ZnO nanoparticles. A Box-Behnken (BB) design with three factors and three center points was used.

1. INTRODUCTION

Self-cleaning construction materials have attracted exceptional attention for their inescapable role in water and air pollution control and their durability (Awadalla, Zain, Kadhum, & Abdalla, 2011; Paolini, Borroni, Pedeferri, & Diamanti, 2018; Qualharini, Stolz, Martini, Polesello, & da Silva, 2023; Xia et al., 2023). The integration of this type of material has become more urgent with the huge increase in the sources of domestic and industrial pollution affecting air and water quality (Deng, 2021; Karpińska & Kotowska, 2019; Singh, Yadav, Kathi, & Singh, 2022). In order to eliminate any residual pollution from surface water, it is necessary to apply advanced oxidation techniques (AOT) which can be envisaged for the destruction of traces of residual pollution (Lee & Park, 2013; Pattnaik, Sahu, Poonia, & Ghosh, 2023; Yao et al., 2023). Among these techniques we can cite: Ozonation, the use of UV rays and photo-catalysis. Zinc oxide nanoparticles, is considered one of the most important photo-catalyst for organic pollutant degradation (Mishra, Pandey, & Fosso-Kankeu, 2023; Wouters et al., 2023). In the other hand, the water scarcity in Saudi Arabia is one of the most important contemporary problems and is of great interest at the research level. The strategic studies of the Ministry of Environment, Water and Agriculture in KSA showed the urgent need to rationalize the demand for water, which was estimated at more than 25 billion cubic meters with an annual increase of 8% (Alrwis et al., 2021; Baig, Alotibi, Straquadine, & Alataway, 2020). It is in this approach that the national and international demand for the development of adequate water treatment techniques and the use of self-cleaning material has become a major preoccupation (Hassan, Yilbas, Al-Sharafi, Sahin, & Al-Qahtani, 2020; Wu et al., 2021). Many of discovered pollutants, especially persistent organic pollutants POPs, are not degradable by conventional water treatment methods. Consequently, it is necessary to apply advanced oxidation (AOT) such as photo-catalysis. Advanced oxidation process (AOP) relies on the production of highly reactive oxidative species, particularly OH° radicals, in particular because of its non-selectivity (Gaur, Dutta, Singh, Dubey, & Kamboj, 2022; Iqbal, Yusaf, Usman, Hussain Bokhari, & Mansha, 2023). Advanced treatment of water is mainly based on photo-catalysis which encompasses a variety of reactions including decomposition processes of chemical species (Caudillo-Flores, Muñoz-Batista, Fernández-García, & Kubacka, 2022; V. Singh et al., 2022). When it is exposed to UV radiation, the photons are absorbed and an electron migrates to the conduction band leaving a hole in the valence band (Van Thuan et al., 2022). Modern photo-catalytic applications involve doping with fluorescent nanoparticles. It promotes the reduction of the electron-hole recombination phenomenon and enhance catalytic efficiency. The significant specific surface area (surface to volume ratio) of nanomaterials improves the adsorption of contaminants and the degradation of pollutants (Napoli, Uriarte, Garrido, Domini, & Acebal, 2022; Ningthoujam et al., 2022; Song et al., 2022). ZnO is frequently applied to reduce water pollution through advanced oxidation processes and is widely employed as a semi-conductor photo-catalyst (Abukhadra, AlHammadi, Khim, Ajarem, & Allam, 2022; Modi et al., 2022). The majority of nanoparticles qualities are closely correlated with its size and shape. By using a series of hydrolysis-condensation reactions, metal alkoxides, which are primarily composed of a metal atom encircled by simple alkyl groups, are converted into nanoparticles. Due to a phenomenon known as "quantum confinement," the major property of semiconductor nanocrystals is that their band gap can be altered in accordance with their size (Ahamed, Ahamed, Kumar, & Sivaranjani, 2022; Torres-Torres & García-Beltrán, 2022). The gap widens and the energy levels are constrained to discrete values as a result of the charge carriers' need to take more kinetic energy in order to penetrate the nanocrystal. The energy structure transitions from a band structure to a discrete level structure as a result of the nanometric size of the nanocrystals (El-Morsy, Awwad, Ali, & Menazea, 2022; Kalyani & Dhoble, 2023). Thus, the properties of the nanoparticles are intermediate between those of the bulk material and those of the molecular compounds, and the theory of the

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مواد تشييد ذاتية التنظيف لإزالة تلوث المياه باستخدام التحلل التحفيزي الضوئي للبنفسج الكريستالي بواسطة محفز الجسيمات النانوية ZnO

يحيى صالح العساف

(قدم للنشر في 1444/9/6؛ وقبل للنشر في 1444/11/11هـ)

مستخلص البحث: لقد اجتذب دور مواد البناء ذاتية التنظيف في تقليل تلوث المياه إلى جانب متانتها الكثير من الاهتمام. أصبح إدراج هذه المواد الآن أكثر أهمية من أي وقت مضى بسبب الزيادة الهائلة في مصادر التلوث المنزلية والصناعية التي تقلل من جودة المياه. يعتبر تطبيق الخرسانة ذاتية التنظيف ذات التحفيز الضوئي لإزالة الشوائب العضوية من الماء الاعتبار الرئيسي لهذا العمل. باستخدام منهجية سطح الاستجابة (RSM) ، تم تحسين التصميم التجريبي لتخليق الجسيمات النانوية. تمت دراسة تأثير سرعة التحريك ودرجة الحرارة وتركيز خلات الزنك على قطر الجسيمات النانوية. تم استخدام تصميم Box-Behnken (BB) مع ثلاثة عوامل وثلاث نقاط مركزية. يتأثر حجم الجسيمات المصنعة بدرجة كبيرة بدرجة الحرارة. تم إجراء نتائج تحلل نموذج الملوثات (Crystal Violet (CV)) لأحجام مختلفة من الجسيمات المركبة (14.2 نانومتر ، 16.8 نانومتر ، 19 نانومتر) ومتوسط حجم الجسيمات من ZnO التجاري (50 نانومتر). أظهرت النتائج أن تقليل حجم الجسيمات من 50 نانومتر إلى 14.2 نانومتر يحسن معدل التحويل الأقصى بنسبة 33٪ ويسرع معدل التفاعل بنسبة 28٪. ينخفض تركيز الملوث تدريجياً ليصل إلى قيم 4.30 مجم / لتر و 1.80 مجم / لتر و 0.85 مجم / لتر لكل الأوقات 5 دقائق و 10 دقائق و 23 دقيقة. أقصى معدل تحويل تم تحقيقه هو 91.5٪. أخيرًا ، للتحقق من صحة النموذج العددي الذي يحاكي كتلة الرصف الخرسانية ذاتية التنظيف ، تم إجراء مقارنة بين معدلات التفاعل التجريبية والنمذجة. نتائج النمذجة تتطابق بدقة مع النتائج التجريبية.

كلمات مفتاحية: التنظيف الذاتي، كتلة الرصف الخرسانية، الجسيمات النانوية، المحفز الضوئي، منهجية سطح الاستجابة، النمذجة والمحاكاة.

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Self-cleaning Construction Material for Water Depollution Using Photo-catalytic Degrdation of Crystal Violet by ZnO-nanoparticles Catalyst

Yahya Alassaf

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Abstract: The role of self-cleaning building materials in reducing water pollution besides their durability has attracted a lot of consideration. The inclusion of this material is now more important than ever due to the dramatic increase in domestic and industrial pollution sources that degrade water quality. The application of photo-catalytic self-cleaning concrete to remove organic impurities from water is the major consideration of this work. Using a response surface methodology (RSM), the experimental design for nanoparticle synthesis was optimized. The effect of stirring speed, the temperature and the concentration of zinc acetate on the nanoparticles diameter were studied. A Box-Behnken (BB) design with three factors and three center points was used. The size of the synthesized particles is most significantly influenced by temperature. The degradation results of the pollutant model (Crystal Violet (CV)) are carried out for different sizes of synthesized particles (14.2 nm, 16.8 nm, 19 nm) and an average particle size of commercial ZnO (50 nm). The results show that decreasing the particle size from 50 nm to 14.2 nm improves the maximum conversion rate by 33% and accelerates the reaction rate by 28%. The concentration of pollutant decreases gradually to reach the values of 4.30 mg/L, 1.80 mg/L, and 0.85 mg/L for the respective times 5min, 10min and 23min. The maximum conversion rate achieved is 91.5%. Finally, to validate the numerical model simulating the self-cleaning concrete paving block, a comparison of the experimental and modeled reaction rates was established. The modeling results accurately matched the experimental results.

Keywords: Self-cleaning, Concrete paving block, Nanoparticles, Photo-catalyst, RSM, Modeling and simulation.

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Figure 12 illustrates the hardness of composites in HV for various compositions. The hardness is commensurate with the mean of hard reinforcing particles. The trend of the hardness is proportional to the hardness of the particulate, and it improved proportionally with the increase in the amount of reinforcement. For the 8% weight fraction of micro particulate inclusion, maximum hardness in alumina reinforced composites was enhanced by 28.5%, by 19% for silica reinforcement, and by 53% for boron carbide.

4. CONCLUSION

Aluminum Alloy AA 6063 based composites were produced by the liquid fabrication method. Stir casting technique and composites were made by nanoreinforcement, with the addition of 0.5% wt. of functionalized MWCNTs constantly in all compositions. The composites were further reinforced by different microparticulates by varying the quantity of SiC, Al_2O_3, and B_4C, each of which was reinforced in AA 6063 at 2%, 4%, 6%, and 8% by wt. in order to study the effect of microparticulate reinforcement on the mechanical properties of composites. The following conclusions have been drawn:

1. MWCNTs enhance the interfacial bonding of reinforcement and matrix by an effective doping mechanism, thus improving the mechanical and physical characteristics of the composites.
2. The surface topography of the composites had an equal and nearly uniform distribution of reinforcement and MWCNTs acted as binding agents by filling the microgaps between solid reinforcement particles and matrix crystals. This improved the composites' ductile properties and reduced brittleness.
3. In the density evaluation, it was noted that the porosity of the composites was significantly reduced with the integration of MWCNTs in composites. With the increase in the amount of particulate reinforcement, porosity also increased. The porosity of SiC reinforced composites exhibited higher porosity than that of B_4C and Al_2O_3 composites. Hardness was enhanced proportionally with volume of reinforcements, as seen that 8% wt. fraction. Hardness was improved by 57%, 46%, and 85% for the Al_2O_3, SiC, and B_4C reinforcements, respectively.
4. Tensile strength improved with the increase in the amount of reinforcement. The highest σt was observed at 6% wt. of particulate reinforcements, beyond which it deteriorates. UTS improved by 78%, 65%, and 232% for an Al_2O_3, SiC, and B_4C reinforcements, respectively
5. Compression strength and hardness increased linearly, with the highest levels found at 8% wt. of reinforcement and enhancement in σ_c. Hardness levels were 57%, 46%, and 85% for Al_2O_3, SiC, and B_4C reinforcements, respectively.
6. SEM micrographs showed the fracture mechanism of the tensile test in composites. It was found that stretch due to axial pull had peak formation and partial tensile striations due to the uniform dispersion of reinforcements. The fracture is caused by instant crack and failure. The microstructure at residual fracture area clearly shows the distribution and bonding between the ceramic particles and the Al matix. In some areas, agglomeration of MWCNTs embrittled the material and resulted in the rapid disengagement of reinforcing particles. Overall, the dispersion of particulates was effective on composites.

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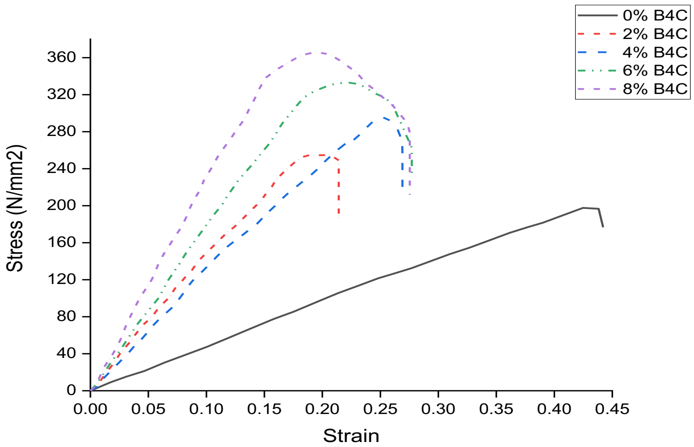


Figure (11c)

Figure 11: Stress-Strain diagrams of AA 6063 based composites under compression with constant 0.5% MWCNTs and variable micro particulate reinforcements of (a) Al_2O_3; (b) SiC; and (c) B_4C with variable quantity by 2%, 4%, 6%, and 8% wt.

Figure 11 shows characteristic curves of stress vs strain of the Al matrix composites with variable micro and fixed nanoreinforcements. In the graphs, it was observed that the compression strength of composites was significantly increased with the increase in the number of reinforcements. Because the density of composites was also enhanced, the load-carrying capacity of the composites under compression was improved. Here, B_4C reinforcement has shown a substantial increase in strength, followed by alumina and silica. Silica-reinforced composites exhibited a strength enhancement of 46%, alumina reinforced composites by 57%, and boron carbide reinforced composites by 85% (each for 8% weight fraction of composites).

3.5. Hardness Test

Measurement of the composites' hardness is crucial for determining composites' machinability and surface reliability under the influence of abrasion/erosion or indentation. The compositions' hardness was measured using Vicker's hardness test.

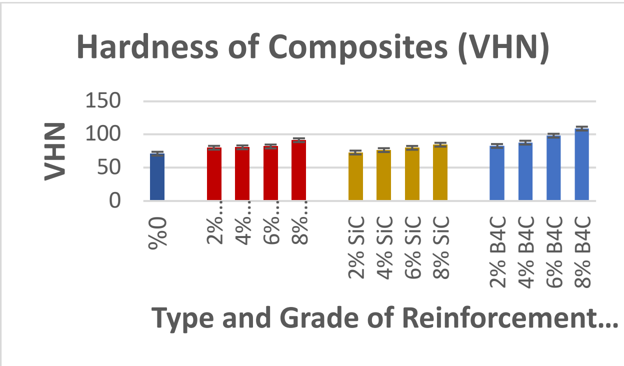


Figure 12: Hardness of the Al matrix composites with variable reinforcements

hardness and brittleness of the material. AA 6063 was force blended and followed by CNT's bonding effect. As a result, striations can be seen in the areas of partial mixture, whereas CNT's influence on matrix reinforcement binding was observed. The strongest composite was observed with reduced elongation and enhanced hardness.

3.4. Compression Test

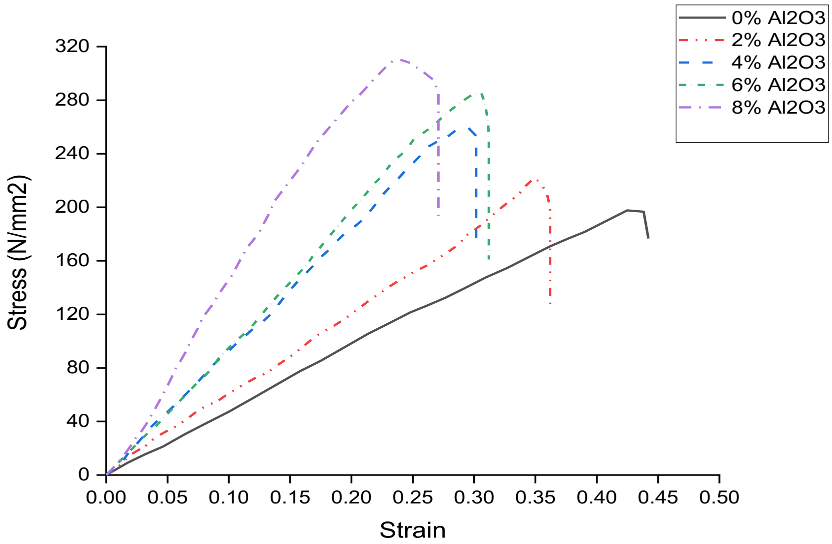


Figure (11a)

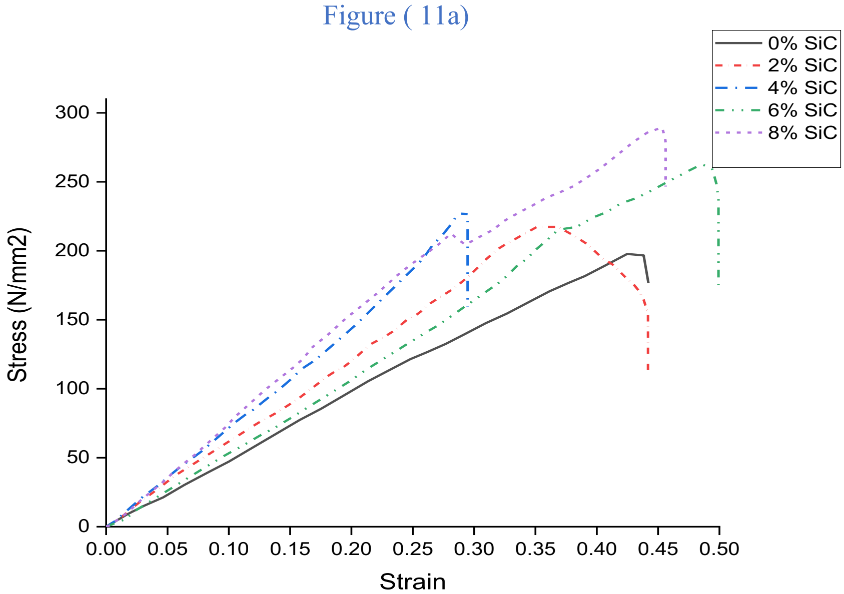


Figure (11b)

Figure 9 shows the stress-strain curve, projecting tensile characteristics of B_4C-reinforced Al composites. The B_4C reinforcement substantially reduced the total extension/elongation of the composites, but it significantly enhanced the strength. This is due to B_4C having a lower density than the Aluminum alloy. The lower density makes the homogenization of the matrix reinforcement mixture more difficult, but the integration of MWCNTs improved the wettability issues, which enhanced interfacial bonding and aided in effective doping of reinforcing atoms in the Al matrix. In the composites, tensile strength increased linearly with increases in reinforcement but began to deteriorate after 6% integration of B_4C by weight. The UTS was enhanced by 2.3x, the elastic modulus by 6.5x, and subsequent elongation was reduced by 42%.

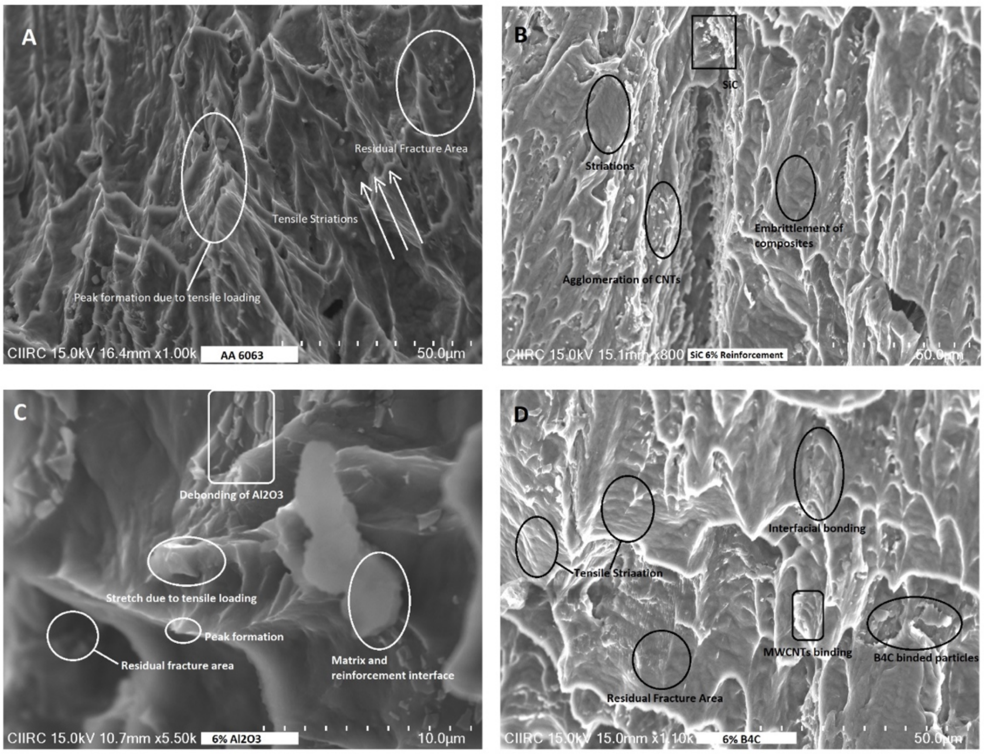


Figure 10. SEM fractographs of (A). Al 6063 with no reinforcements and composites with constant 0.5% wt. MWCNTs; at (B) 6% wt. SiC; (C) 6% wt. Al_2O_3; and (D) 6% wt.

The fracture mechanism of AA 6063-based composites is as shown in figure 10. The fractpographs in Figure A indicate that aluminum alloy 6063 exhibits more tensile striations due to the highly ductile nature whereas, in reinforced composites, striations are considerably lowered. This indicates that brittleness is introduced along with the introduction of hard ceramic particles. Figure B shows the agglomeration of MWCNTs in some areas, but nanotubes greatly influenced SiC particles' bonding with aluminum. Figure C illustrates the fine Al_2O_3 particles bonding effectively due to the mutual atomic doping and diffusion. This doping and diffusion cause atomic transfusion with base aluminum and mixes with it at high temperature. However, formation of alumina clusters was observed in some areas. Furthermore, MWCNTs enhanced the interfacial bonding of alumina with based aluminum. In Figure D, B_4C particles (which are significantly harder and has lower density than AA 6063) bonded moderately, causing the increase in with micro and nano-reinforcements up to the critical reinforcement of 6% by weight, beyond which the tensile strength decreased. Furthermore, the strain or extension at 6% of Al_2O_3 reinforcement is lower, which indicates embrittlement of material and improper placement of atoms in crystals. This embrittlement results in microcracks and improper bonding of alumina particles with AA 6063. Overall performance of the composites under tension improved with the addition of reinforcements. It was observed that the maximum UTS is improved by 78% for 6% of Al_2O_3 and 0.5% of MWCNTs. The subsequent elastic modulus was improved by 2.8x. The ductility of the composites was compromised with the integration of Alumina. Ductility decreased with increases in the amount of reinforcement and for 6% of alumina, it was reduced by 43%.

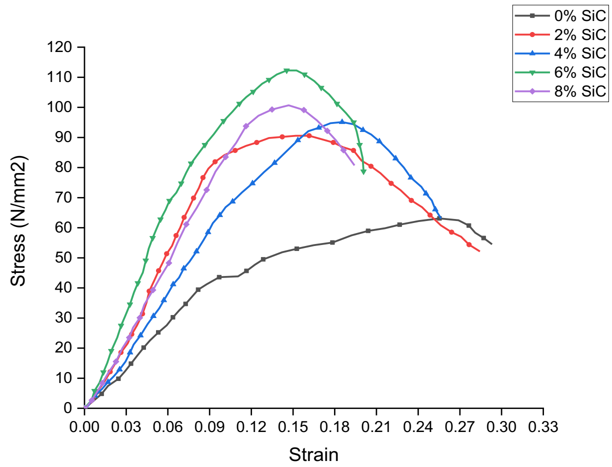


Figure 8: Stress-Strain curves of AA 6063+ 0.5% MWCNTs + SiC Composites tested under tension with variable Silica quantity by 2%, 4%, 6%, and 8% wt.

In Figure 8, characteristic curves of stress-strain under tension were observed. In SiC reinforcement with MWCNTs, the tensile strength significantly improved and was highest at 6% wt. of SiC, while the corresponding strain was enhanced at lower levels. The elastic modulus reduced the elongation/ductility of the composite. In the composition, tensile strength was ultimately enhanced by 65% and modulus by 3.3x for 6% wt. of SiC with 0.5% wt. of MWCNTs.

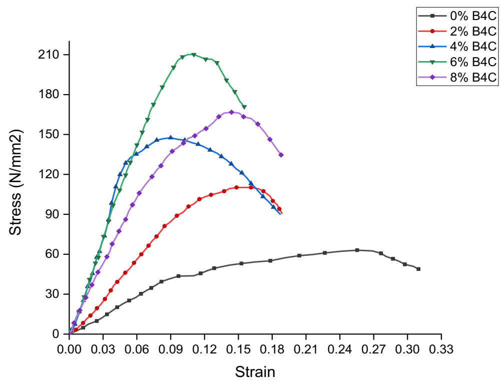


Figure 9: Stress-Strain curves of AA 6063+ 0.5% MWCNTs + B_4C Composites tested under tension with variable Boron carbide quantity by 2%, 4%, 6%, and 8% wt.

Table 2: Tensile Properties of Composites with Varied Reinforcements

Composites	Young's Modulus *(N/mm²)*	Ductility/ Elongation *(%)*	UTS Improvement *(%)*	Modulus Improvement *(%)*
0%	336.12	32.48	--	--
2% Al_2O_3	1016.64	31.58	43.58	202.46
4% Al_2O_3	724.11	26.90	50.76	115.43
6% Al_2O_3	1277.19	18.39	77.96	279.97
8% Al_2O_3	871.14	27.67	59.60	159.17
2% SiC	751.26	28.44	46.43	123.51
4% SiC	626.31	25.65	48.54	86.332
6% SiC	1458.7	20.07	65.26	333.98
8% SiC	537.33	19.42	52.53	59.86
2% B_4C	1043.46	18.89	74.63	210.44
4% B_4C	3133.95	18.74	133.91	832.38
6% B_4C	2546.17	15.52	232.91	657.51
8% B_4C	1649.97	18.79	164.36	390.88

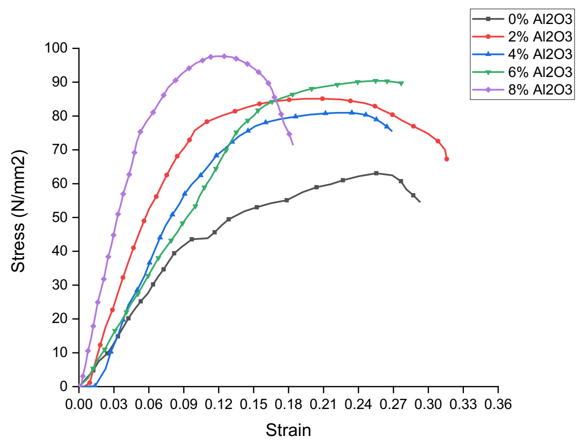


Figure 7: Stress-Strain curves of AA 6063+ 0.5% MWCNTs + Al_2O_3 Composites tested under tension with variable alumina quantity by 2%, 4%, 6%, and 8% wt.

Figure 7 shows the stress-strain curves of Al matrix composites with different grades of alumina-reinforced composites. It was observed that the composites showed improved strength

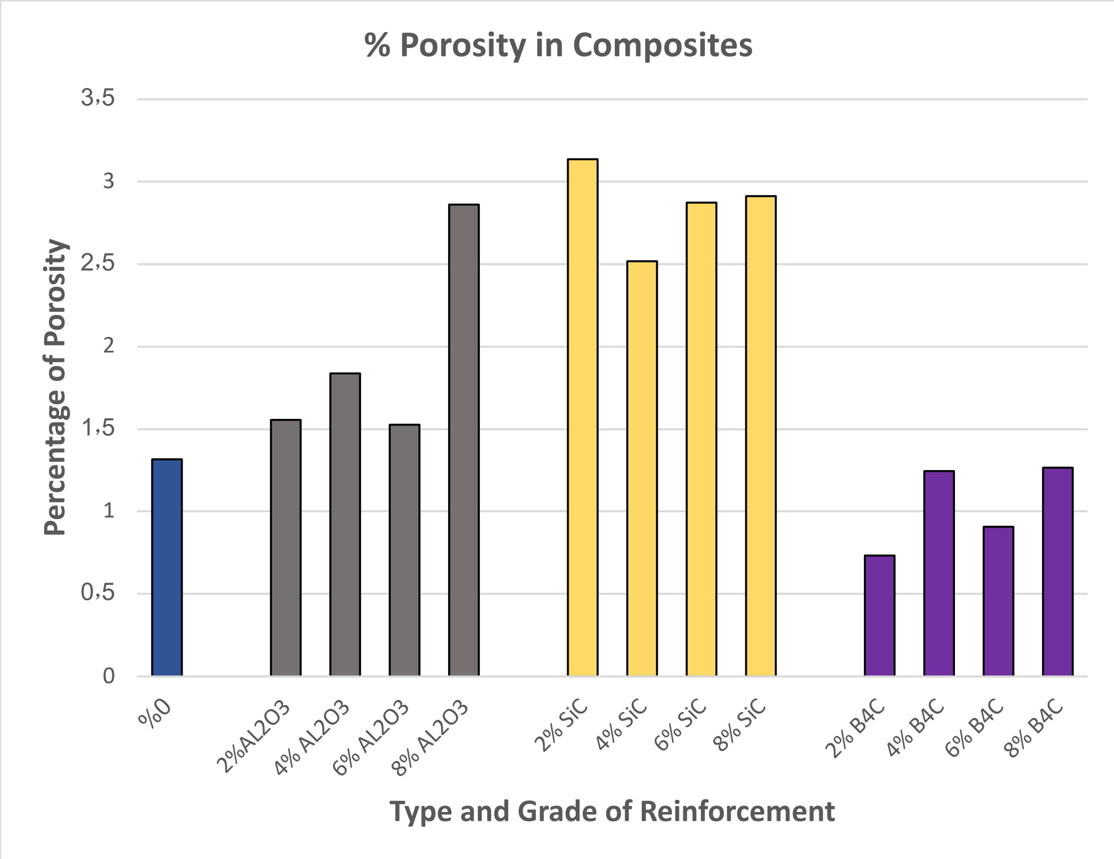


Figure 6: Volume Void Fraction or Porosity of Composites with Different Weight Fractions of Particulate Reinforcements SiC, Al_2O_3, and B_4C

Experimental density decreased due to the blend of two distinctly characterized materials, resulting in void volume or porosity in composites (Fig 6). The change in atomic arrangement and mechanical crystal structure caused atomic vacancies, substitutional deficiencies, and improper interfacial bonds. This contributed to the formation of microcracks and gaps between the Al matrix and non-homogenized particles of composites. B_4C-reinforced composites reacted more with MWCNTs in forming an effective blend and a reinforcement bond with the Al matrix. Reduction of porosity was largely attributed to the functionalized CNTs, which fill the micro /nano gaps and act as agents in reinforcing the composites' bond.

3.3. Tensile Test

The tensile strength of Al 6063 matrix composites with SiC, Al_2O_3, and B_4C reinforcements was measured by maintaining a constant 0.5% weight fraction of MWCNTs and varying microparticulate reinforcement by weight at 2%, 4%, 6%, and 8%. Table 2 shows the tensile properties of composites and the enhancement of tensile strength and modulus by integration of reinforcements in aluminum alloy AA 6063.

2% B_4C	2655.06	2647.73	0.7331177
4% B_4C	2653.68	2641.23	1.2453505
6% B_4C	2652.30	2643.23	0.9075832
8% B_4C	2650.92	2638.27	1.265816

Table 1 shows the theoretical and experimental densities of the composites. By varying the quantity of different particulate reinforcements, we can notice the volume void fraction of the composite termed as porosity in composite blocks.

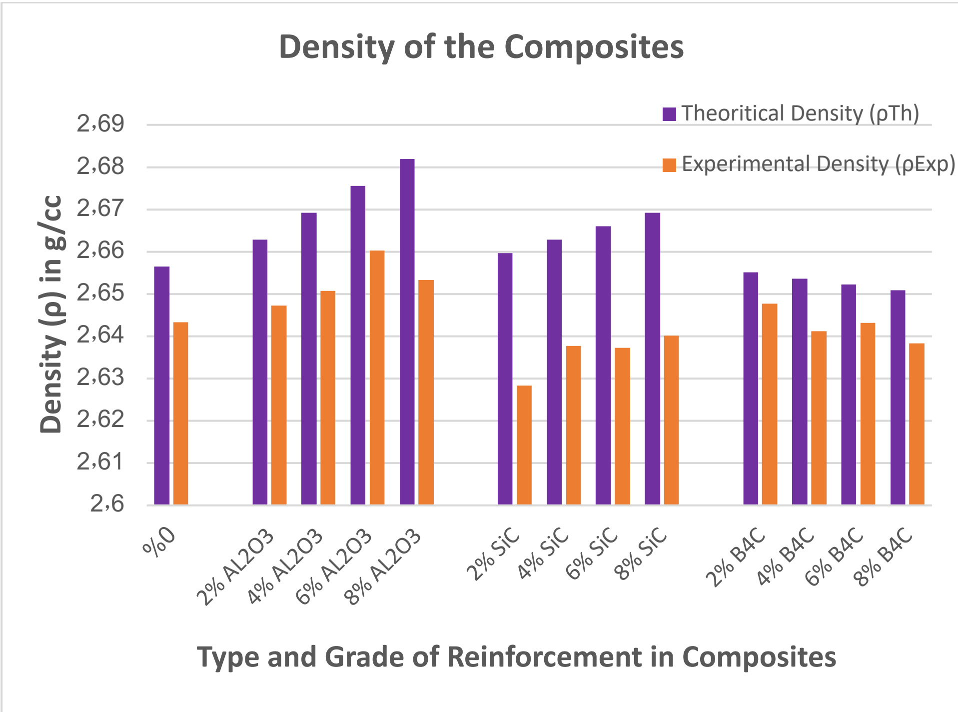


Figure 5: Theoretical and Experimental Densities of Composites with Different Weight Fractions of Particulate Reinforcements SiC, Al_2O_3, and B_4C

Figure 5 compares the theoretical and experimental densities of composites. It was found that the density of composites increased in SiC reinforcement and that it increased linearly with the number of reinforcements because SiC is denser than the AA 6063 alloy. In alumina and B_4C reinforcements, theoretical and experimental densities were reduced due to the fineness and lowered density of the reinforcing agent. Furthermore, in the B_4C reinforcement, the density was lower than base AA 06063. The density of B_4C reinforcement is lower than that of the matrix element, and with the rise in weight fraction of reinforcements, there is an overall reduction of densities in composites.

Silicon Carbide was found in aluminum in the form of microflakes and is the cause of improper homogenization of reinforcement elements. The graphs thus show an artificial doping mechanism of SiC in Al 6063 as the carbon atoms form effective interstitially, which subsequently enhances the compressive strength. It was also found that MWCNTs act as interfacial bonds between the SiC and Al matrix, with adequate consistency in the formation of composites. The micrographs (Figure 4a) depict the greater influence of MWCNTs over SiC in bonding with the Al matrix. The material is expected to be hard, brittle, and highly resistant to wear.
Alumina particles can be seen clearly in the microstructure (Figure 4b). There is a nearly uniform distribution of reinforcement in the Al matrix. Al_2O_3 was reinforced into Al 6063 with an 8% weight fraction and also with 0.5%wt. of the composite, resulting in optimum doping of alumina particles and CNTs into a metallic matrix. This improved the dispersion and bonding of ceramic particulate and Al matrix, thus enhancing the mechanical and tribological characteristics of the material.
Boron carbide with MWCNTs integration in Al 6603 has substantially homogenized and exhibited atomic influence of matrix materials. Figure 4c illustrates its substitution in Al crystals. It was found that excessive reinforcement of B_4C leads to more general wettability issues due to its lower density. But in micrograph light, plough marks are seen and effective substitution of reinforcement is attributed to MWCNTs. However, the microstructure shows an obvious effect of particulate/atomic slip in matrix crystals due to the hardness and lightness of B_4C.

3.2. Density and Porosity

Density measurement of the composites is a practical approach to evaluating porosity, which is a common defect found in composites due to the fundamental heterogeneity of elements of composites. Effective engineering is needed in order to develop the composites with maximum blend efficiency. The conventional way of determination of density (by geometrical means and using the mass/volume method) was adopted and compared with the theoretical evaluation of density. The difference between theoretical and experimental density determines the porosity in composites.

Table 1: Density and Porosity of Composites with Varied Particulate Reinforcements

Composites	Theoretical Density (ρ_{Th})	Experimental Density (ρ_{Exp})	% Porosity
0%	2656.43	2643.27	1.317
2% Al_2O_3	2662.79	2647.24	1.556
4% Al_2O_3	2669.15	2650.78	1.837
6% Al_2O_3	2675.51	2660.25	1.526
8% Al_2O_3	2681.87	2653.26	2.861
2% SiC	2659.64	2628.28	3.136
4% SiC	2662.84	2637.67	2.5176314
6% SiC	2666.05	2637.32	2.8730046
8% SiC	2669.25	2640.13	2.9123779

measurement. A Vickers microhardness test was carried out using diamond indentor.

Morphology: Composites samples were ground using various grid-sized emery papers in sequence from lower numbers to up to 2000 grids. The surface was buffed with cotton, then polished using velvet, alumina powder, and diamond powder. Finally, the carefully polished surface was etched using HNO_3 and HCL to normalize the micropeaks on the surface of the samples. After ensuring that the surface was fully polished, the surface microstructure, grains, inclusions, and surface properties were studied using an inverted metallurgical microscope in various magnifications up to 1600X.

Density Measurement: Density measurements were performed to determine porosity in the composites. Porosity is a defect at the micro level, so it can be calculated by comparing the theoretical and experimental density of the composites. The composite samples were weighed using a high-precision scale having that measures down to the thousandth of a gram.

Theoretical density (ρ_{Th}) of the composite can be calculated by:

Density of Composite = (Volume fraction of AA 6063 x Density of AA 6063) + (Volume fraction of MWCNTs x Density of MWCNTs) + (Volume fraction of reinforcement 2 x Density of reinforcement 2)

$$\rho_{Comp\ 1} = (Vol_{AA\ 6063}\ X\ \rho_{AA\ 6063}) + (Vol_{MWCNTs} X \rho_{MWCNTs}) + (Vol_{SiC}\ X\ \rho_{SiC}) \quad \ldots\ldots\ (1)$$

$$\rho_{Comp\ 2} = (Vol_{AA\ 6063}\ X\ \rho_{AA\ 6063}) + (Vol_{MWCNTs} X \rho_{MWCNTs}) + (Vol_{Al2O3}\ X\ \rho_{Al2O3}) \ldots\ (2)$$

$$\rho_{Comp\ 3} = (Vol_{AA\ 6063}\ X\ \rho_{AA\ 6063}) + (Vol_{MWCNTs} X \rho_{MWCNTs}) + (Vol_{B4C}\ X\ \rho_{B4C}) \quad \ldots\ldots\ (3)$$

Experimental density (ρ_{Exp}) can be obtained by precise measurement of sample weight divided by the volume of the sample

Porosity can be calculated by:

$$\%\ Porosity = \frac{(\rho Th - \rho Exp)}{\rho Th}\ \text{x}\ 100 \quad \ldots\ldots\ (4)$$

3. RESULTS AND DISCUSSIONS:

3.1. Morphology and crystallography

The surface characteristics of composites influence several physical and mechanical properties. As a result, studying surface topography and microstructure is important for characterizing the materials.

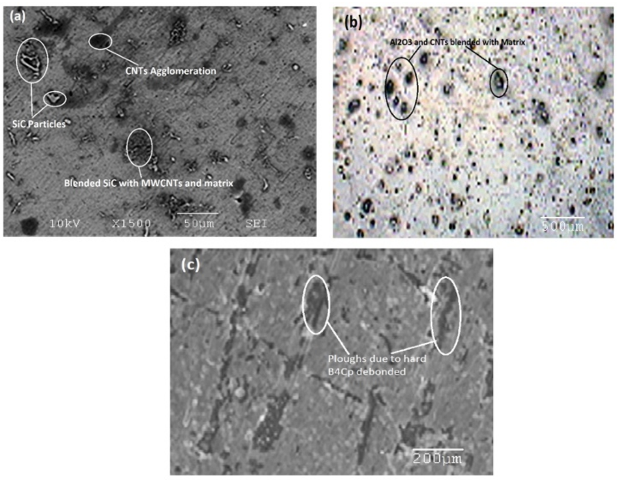


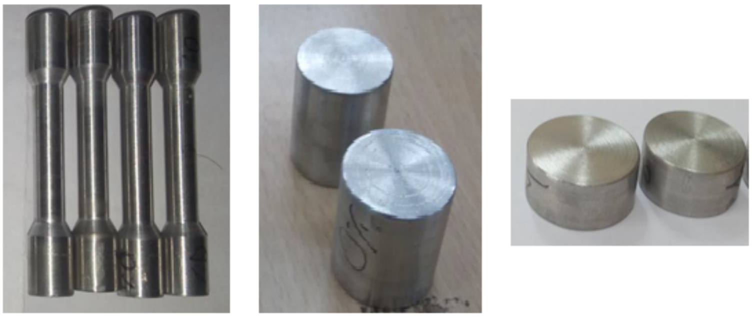
Figure 4: Microstructure of Al 6063 based composites surface for (a) 6% wt. SiC; (b) 6% wt. Al_2O_3; and (C) 6% wt. B_4C

Removal of Moulds from Moulding box

Figure 2: Post casting aluminum composite molds

2.3. Testing and Validations:

After casting was complete, AMC molds were machined and specimens were drawn for mechanical testing according to the geometries and testing standards described by ASTM viz, E8 for Tensile Testing (Figure 3a), E9 for Compression testing (Figure 3b), and E384 for Vickers Hardness (Figure 3c).



(a) **(b)** **(c)**

Figure 3: Specimens for (a) Tensile Test; (b) Compression Test; and (C) Hardness Test and Morphology

Tensile Test: A uniaxial tensile test was performed on an electromechanically operated, computer-controlled universal testing machine at room temperature at a loading rate of 10 MPa per second (following ASTM E8- M91 standards). The load vs. displacement and stress-strain curve generated was used to analyze the mechanism of fracture.

Compression Test: A uniaxial compression test was performed using AMCs in a computerized UTM to study the effect of axial compression on material and failure under compression (following ASTM E9 standards).

Hardness Measurement: Composites samples were carefully polished using various emery papers. Samples were also velvet-buffed and etched when required to achieve a clear surface. Following ASTM E384 standards, samples were then subjected to microindentation for hardness to develop composites for wide applicability; high functionality; minimized cost of material; low density; high levels of durability, endurance, and machinability; improved thermal and/or electrical properties; and advanced static and dynamic load-sustaining capabilities. Aluminum often fulfills various structural and mechanical requirements because it is lightweight, easy to machine, and easy to fabricate. For these reasons, commercially available standard aluminum alloy 6063 was selected to matrix the composites. To reinforce the composites, silicon carbide, aluminum oxide, and boron carbide particulates were chosen as primary reinforcement. Additionally, to enhance the blend/mixture of matrix and reinforcements, carboxyl (COOH) functionalized multi-walled carbon nanotubes were used as secondary reinforcement. Nanotubes were selected because of their excellent interfacial bonding capabilities. Reinforcement particles were subjected to ball milling to minimize the particle size, which optimized the blend of matrix and reinforcements. The particles were resized to 15-50μm. SiC, Al_2O_3, and B_4C were reinforced individually in AA 6063 to study the effect of microparticulates in composites in the weight fractions of 2%, 4%, 6%, and 8% [with a constant weight fraction of 0.5% nano reinforcement (Multi-walled carbon nanotubes -MWCNTs) in each composition].

2.2. Fabrication and processing:

AMCs were fabricated using a stir casting melting technique. Stir casting setup as shown in (Figure 1), consist of a furnace, reinforcement feeder and mechanical stirrer. It is the most suitable process for metal matrix composites, because it allowed experimenters to blend hard/light particles in molten metal and disperse them using a stirrer for the weight fractions of reinforcements up to 30%. The mechanical stirrer used in this investigation rotated at a speed of 600RPM. The matrix was heated to 730ºC. Particulate reinforcement was added to matrix by preheating to 300ºC for 5 minutes. This heating improved the wettability of MWCNTs at room temperature. Now, the molten AMCs composites are poured into the mold and allowed to solidify. The moulds are taken out after solidification from the moulding box (Figure 2).

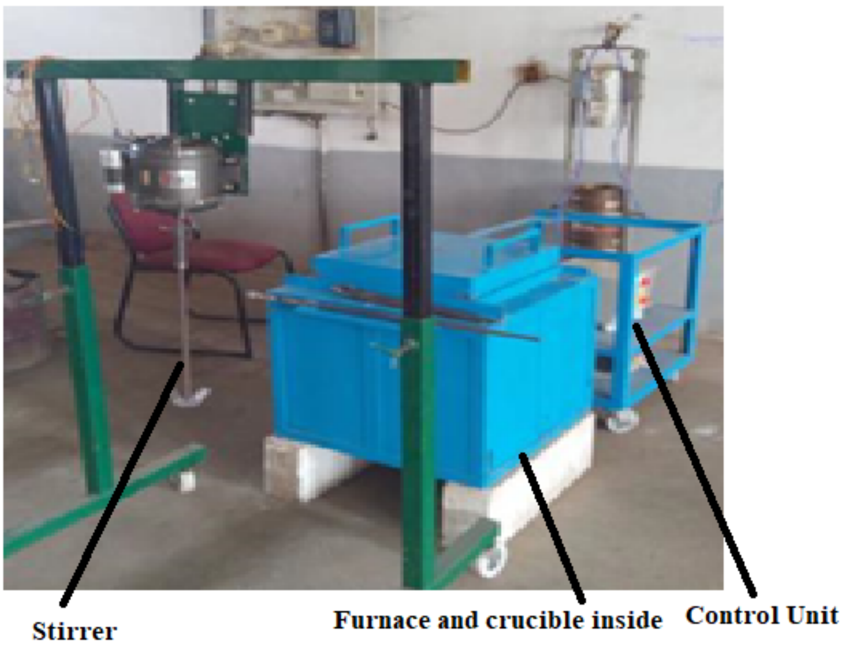


Figure 1: Stir casting furnace

223% (Auradi, Rajesh & Kori, 2014). When the examination was done on the effect of nano reinforcement (CNTs) in AA 6063, they found that by using a hot extrusion process, 3% vol. of CNTs in composites resulted in a high Vickers hardness of 120 HV, recrystallization zone projected excellent hardness, strength, and ductility which is evidenced by dimples seen in microstructures (Kim, Park, Kim, Miyazaki, Joo, Hong, & Kwon, 2019). The hybrid nanocomposites based on aluminum alloy 6061 reinforced with different hybrid ratios of SiC (0.5, 1.0 and 1.5 vol. %) and B4C (fixed 0.5 vol. %) nanoparticles were successfully fabricated using ultrasonic cavitation-based solidification process. The fabricated cast specimens were characterized using SEM study with EDS analysis, hardness test, tension test and impact test. The results indicate that, Compared to the un-reinforced alloy, the room temperature hardness and tensile strength of the hybrid composites increased quite significantly while the ductility and impact strength reduced marginally. The combination of 1.0 volume percentage SiC and 0.5 volume percentage B4C gives the superior tensile strength. The major reason for an increase in the room-temperature mechanical properties of the hybrid composites should be attributed to the larger hybrid ratio of SiC and B4C nanoparticles, the coefficient of thermal expansion mismatch between matrix and hybrid reinforcements and the dispersive strengthening effects. (Poovazhagan, Kalaichelvan, Rajadurai, & Senthilvelan, 2013). When investigation was done on the mechanical properties of AA 6063 based composites reinforced with constant 1% Wt. of alumina and varying graphite with 3%, 6%, 9%, and 12% Wt. They found that hardness, compressive strength, flexural strength, and impact strength increased with an increase of reinforcement up to 6% of the weight. Further increase in reinforcement resulted in a decrease in these properties (Saravanakumar, Sasikumar, & Sivasankaran, 2014). It was observed that the significant advancements of mechanical properties such as UTS (ultimate tensile strength), compressive strength, and hardness in AMCs. With the integration of CNTs and graphenes, strength has increased by up to 5x (Khanna, Kumar, & Bansal, 2021). When the study was done on the influence of SiC and B4C particulate reinforcement in aluminum-based composites. They found that silica and boron carbide greatly enhanced the mechanical and physical properties, whereas TiB2 integration deteriorated in Al composites (Kumar, Dabade, & Wankhade, 2021). Aluminium alloy surface hybrid nanocomposite, reinforced with boron carbide (B4C), aluminium oxide (Al2O3), and Graphite (Gr) at different combination mixtures by weight ratio have been fabricated on Al7075-T6 aluminium plate by employing friction stir processing (FSP). The hybrid nanocomposite having a reinforcement mixture of 30 B4C+60 Al2O3+10 Gr exhibits a significant wear resistance than other combination ratios. This is endorsed by the enhancement in binding strength of the matrix and the pinning effect of hard reinforcements, which act against the applied shear force. (Gobikannan, Gopalakannan & Balasubramanian, 2022)

Tensile strength and Young's modulus are required in almost every mechanical investigation. To meet the functional requirements of the industry, aluminum composites with different types and grades of reinforcement (which exhibit varied strength and mechanical properties) have been developed. To design the material for specific applications, researchers must choose the right level of reinforcement.

In the present work an attempt is being made to process AA 6063 matrixed composite by systematically dispersing COOH functionalized MWCNTs as primary reinforcement with a constant weight of 0.5% by stir casting method. Further, Alumina (Al2O3), Silica (SiC), and Boron Carbide (BFC) were reinforced individually in Aluminum alloy AA 6063 with sequential weight fractions equivalent to 2%, 4%, 6%, and 8% by weight of Aluminum Oxide, Silicon carbide, and Boron carbide. The composites prepared were subjected to evaluation of mechanical properties and the improvement achieved is noted down.

2. EXPERIMENTAL METHODOLOGY:

2.1. Materials and Methods:

The selection of materials is a crucial task in any investigation. The prime objective of this study is

1. INTRODUCTION:

The development and manufacturing of composites are influenced by the high demand of industries in various applications. Various engineering applications require composites with high specific strength and durability (Miracle, 2005). The systematic engineering assortment of metallic matrix and ceramic reinforcements leads to the new material delivering exceptional characteristics than that of the conventionally available groups of materials. The new material offers high specific strength, enhanced endurance, resistance against corrosion, improved hardness, toughness, etc., and can further be tailored with the addition of nanoparticles/nanotubes to enhance mechanical, electrical, thermal, hygrothermal, and many other physical properties (Adamiak, 2006), (Aribo, Omotoyinbo, & Folorunso, 2011). Common microparticles such as silicon carbide (SiC), aluminum oxide (Al_2O_3), titanium oxide (TiO2), boron carbide (B_4C), and many other nitrides, borides, carbides, and oxides serve as eramic reinforcement in MMCs. The mechanical, tribological, and thermal properties of hard particulate reinforcement facilitate interfacial bonding with matrices and normalize the properties of elements to achieve a high modulus to density ratio in composites [Marin, Lekka, Andreatta, Fedrizzi, Itskos, Moutsatsou & Kouloumbi, 2012), (Koli, Agnihotri, & Purohit, 2015).

AA 6063 contains Si and Mg as major alloying elements, which allows for its wide applicability. AA 6063's machinability, weldability, and formability produce high levels of strength (Thangarasu, Murugan, Dinaharan, & Vijay, 2014). By precisely engineering the material with the systematic integration of the right amount of reinforcements (Gangil, Maheshwari, & Siddiquee, 2018), (Ali, Kuppuswamy, Soundararajan, Ramkumar, & Sivasankaran, 2021), machining and manufacturing ease can be achieved by using AA 6063. SiC reinforced in aluminum alloy 6603 has shown significant improvement in tensile strength, density, and hardness, whereas particles of Al_2O_3 exhibit better mechanical properties and greater wear resistance compared to aluminium alloy 6603 (Chak, Chattopadhyay, & Dora, 2020), (Singh & Goyal, 2018). When blended with calcium carbide in AA 6063, boron carbide microparticles developed a composite that exhibited significant improvement in mechanical properties, including tensile strength and hardness of AA6063. Impact strength, however, deteriorated with the increase in the quantity of reinforcement (Madheswaran, Sugumar, & Elamvazhudi, 2015). In recent investigations, it was observed that nano reinforcement has improved the mechanical properties of AMCs at higher levels than the microparticle reinforcements.Nano reinforcement in AMCs has greatly improved the characteristics of materials in static and dynamic loading. More specifically, the interfacial bonding was seen significantly enhanced, thus reflecting enhanced properties due to quantum confinement and surface exposure in nanoparticles and nanotubes (Sharma, Kumar, & Joshi, 2019). It was recorded that microparticles generate micro cracks and voids in manufacturing. It was observed that if the weight fraction of ceramic reinforcement is increased above 30% in AMCs, the brittleness of material increases. This brittleness result in low tensile strength and toughness, but the problem can be overcome with the integration of nanoparticles/nanotubes in AMCs, which enriches the interfacial bonding and increases the strength and mechanical characteristics of AMCs (Sharma, Kumar, & Joshi, 2019), (Yang, Lan, & Li, 2004). It was noted that the compressive strength and impact strength of AA 7075+ SiC composites increased with an increase of SiC in AMC. This increase was produced by a liquid metallurgy solidification process. Solutionizing and artificially aging composites to T6 condition further improved the properties and reduced the deflection in 3 point bending. Further increase in SiC was achieved by reducing particle size has enhanced the microhardness but reduced the ductility of AMC in stir-assisted solidification (Das, Sharma, Samal, & Nayak, 2019). It is found that 11% wt. of B4C addition in AA 6061 (in two stages of addition) with 0.3x ratio of K2TiF6 salt in stir casting resulted in improved wettability and uniform dispersion in matrix, resulted in enhancement of UTS by 4.2% and hardness by

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تأثير MWCNTs و SiC / Al_2O_3 / B_4C على الخواص الميكانيكية للمركبات القائمة علىAA 6063

بدر مشبب القحطاني

(قدم للنشر في 1444/8/9؛ وقبل للنشر في 1444/11/11هـ)

مستخلص البحث: هناك طلب كبير على مركبات مصفوفة الألومنيوم لتلبية المتطلبات العملية لمصانع السيارات والمعدات الحربية والفضاء والكهرباء. لتلبية هذه الحاجة ، تم تطوير المواد المركبة من خلال التكامل المنهجي لتعزيز الجسيمات المختلفة بحجم المايكرو والنانو. في هذه الدراسه ، تم تطوير مركبات الألومنيوم عن طريق صبها وتم تصميمها لتحسين الخواص الميكانيكية لمركب مصفوفة **AA 6063** عن طريق تشتيت COOH functionalized MWCNTsبشكل منهجي كتعزيز أولي بوزن ثابت 0.5٪. علاوة على ذلك ، تم تقوية الألومينا **(Al_2O_3)** والسيليكا **(SiC)** وكربيد البورون **(BFC)** بشكل فردي في سبيكة الألومنيوم **AA 6063** بأجزاء متتابعة من الوزن تعادل 2٪ و 4٪ و 6٪ و 8٪ من وزن أكسيد الألومنيوم ، كربيد السيليكون وكربيد البورون. وجدت الدراسة زيادة كبيرة في القوة من خلال التعزيزات الثابتة النانوية والجسيمات الدقيقة المتغيرة في الألومنيوم. كذلك أقصى تحسن في مقاومة الشد ومعامل يونغ لوحظ عند 6٪. لتقوية الجسيمات الدقيقة ل **SiC** و **Al_2O_3** و**B_4C** . تم تحسين قوة الضغط والصلابة بالتناسب مع كمية التعزيز ؛ وبشكل أكثر تحديدًا ، تمت زيادة القوة والصلابة للحصول على أقصى تقوية بنسبة 8٪. من الألومينا والسيليكا والبوريد على التوالي.

كلمات مفتاحية: AA 6063، MWCNTs، SiC، Al_2O_3، B_4C، مصفوفة الألومنيوم المركبة النانوية الهجينة، الخواص الميكانيكية.

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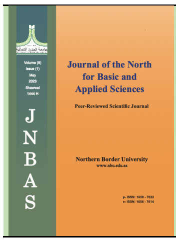

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Influence of MWCNTs and $SiC/Al_2O_3/B_4C$ particulate reinforcements on mechanical properties of AA 6063 based composites

Bader Mushabbab Alqahtani

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Abstract: Aluminum Matrix composites are in high demand to fulfill the functional requirements of the automotive, military, aerospace, and electricity industries. To meet this need, composites have been developed by systematic integration of different particulate reinforcements at the micro and nano-scale. In this investigation, aluminum composites were developed by stir casting and designed to improve the mechanical properties of AA 6063 matrixed composite by systematically dispersing COOH functionalized MWCNTs as primary reinforcement with a constant weight of 0.5%. Further, Alumina (Al_2O_3), Silica (SiC), and Boron Carbide (B_FC) were reinforced individually in Aluminum alloy AA 6063 with sequential weight fractions equivalent to 2%, 4%, 6%, and 8% by weight of Aluminum Oxide, Silicon carbide, and Boron carbide. The study found a significant increase in strength by constant nano and varying micro particulate reinforcements in aluminum. Maximum improvement in Tensile strength and Young's modulus was observed at 6% wt. of microparticulate reinforcement of SiC, Al_2O_3, and B_4C. Compression strength and hardness improved proportionally with the quantity of reinforcement; more specifically, strength and hardness increased for maximum reinforcement of 8% wt. of alumina, silica, and boride respectively.

Keywords: AA 6063, MWCNTs, SiC, Al_2O_3, B_4C, Aluminum matrix hybrid nanocomposites, mechanical properties.

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Rege, Bell, Perlmutter, & Zlokovic, 2015). Additionally, targeting GLUT1 has been suggested as a potential therapeutic approach for the management of Alzheimer's disease, as reducing GLUT1 function may assist in reducing the buildup of amyloid-beta peptide, a significant disease marker (Gejl, Brock, Egefjord, Vang, Rungby, & Gjedde, 2017). Additionally, inhibition of GLUT1 enhanced memory and cognitive performance in a mouse model of Alzheimer's disease, indicating that GLUT1 has been targeted as a therapeutic intervention for Alzheimer's disease (Li et al., 2014).

Targeting GLUT1 may be a promising therapeutic strategy, given the role that GLUT1 plays in the emergence of a number of illnesses. In animal models and early stage clinical trials, GLUT1 inhibition has demonstrated potential for the treatment of diabetes, cardiovascular illnesses, cancer, and neurological disorders. To completely comprehend the mechanisms underlying GLUT1 dysregulation in various illnesses and to establish the efficacy and safety of GLUT1 targeting as a therapeutic intervention in people, additional study is nonetheless required.

The use of GLUT1 inhibitors and imaging techniques based on glucose metabolism are two possible methods for GLUT1 targeting. While these methods have shown promise in preliminary investigations, more analysis is required to properly grasp their therapeutic potential. The development of targeted therapeutics will depend on a comprehensive understanding of the processes by which GLUT1 dysregulation leads to the onset of these disorders, which is another area in need of further study.

The potential for off-target consequences when GLUT1 is the target is one potential drawback. Inhibiting GLUT1 may have unanticipated effects on the absorption and utilization of glucose in other tissues since GLUT1 is expressed in a variety of tissues throughout the body. For example, GLUT1 is essential for glucose reabsorption in late segment in proximal tubules of the nephron completing the 100% of glucose reabsorption (Ghezzi, Loo, & Wright, (2018). GLUT1 is not the sole protein involved in maintaining glucose homeostasis, thus targeting it as a treatment strategy might not be the most effective way to treat all the underlying causes of glucose dysregulation in conditions like diabetes.

Overall, the results of this analysis indicate that GLUT1 targeting may be a feasible therapeutic strategy for a number of disorders, although more investigation is required to completely comprehend the possible drawbacks and advantages of this strategy.

For instance, GLUT2 and GLUT4 are other proteins that play significant roles in the uptake and use of glucose (Bansal et al., 2016). Additionally, other elements like insulin resistance and pancreatic beta cell activity can affect glucose homeostasis (Baker et al., 2012). To effectively address glucose dysregulation in conditions like diabetes, addressing GLUT1 alone might not be adequate; instead, a more all-encompassing strategy might be required.

The results of this research indicate that GLUT1 targeting may be a promising therapeutic strategy for several illnesses, such as diabetes, cancer, and neurological disorders.

As a conclusion, to completely comprehend the mechanisms underlying GLUT1 dysregulation in various illnesses and to establish the efficacy and safety of GLUT1 targeting as a therapeutic intervention in people, additional study is nonetheless required. Furthermore, it is crucial to consider the potential drawbacks and off-target effects of targeting GLUT1 and to think about a more all-encompassing strategy for tackling glucose dysregulation in conditions like diabetes.

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sensitivity and glucose tolerance (Shen, Wang, Xu, Ma, & Zhang, (2014). One study found that targeting GLUT1 with a small molecule inhibitor improved glucose homeostasis in a mouse model of type 1 diabetes. GLUT1 has also been addressed as a therapeutic intervention for type 1 diabetes (Bansal, Chaudhary, & Dhawan, 2016).

Cardiovascular illness has also been associated with GLUT1 dysregulation. Individuals with atherosclerosis have been found to have reduced GLUT1 expression in their endothelial cells, and this reduced GLUT1 expression has been associated with decreased glucose absorption and utilization in these cells (Iwamoto et al., 2020). Atypical GLUT1 expression has also been connected to the emergence of hypertension and other cardiovascular illnesses. Furthermore, GLUT1 has been demonstrated to play a role in the regulation of blood pressure and vascular function (Iwamoto et al., 2020).

Additionally, GLUT1 has been linked to the emergence of cancer, with cancer cells frequently exhibiting high levels of GLUT1 expression (Pawar, Mhatre, & Kucuk, 2011). It has been demonstrated that GLUT1 contributes to the development, proliferation, and survival of cancer cells (Lin, Lin, Chen, & Hsieh, 2013). Cancer cells' growth and viability have been demonstrated to decrease when GLUT1 is inhibited, both in vitro and in vivo (Wang et al., 2016). Breast, ovarian, and pancreatic cancer are only a few cancer types where abnormal GLUT1 expression has been noted (Santra et al., 2020). GLUT1 is frequently overexpressed in cancer cells, which results in enhanced glucose absorption and utilization. This can promote the growth and proliferation of cancer cells (Santra et al., 2020). As a result, it has been suggested that GLUT1 targeting could be a possible therapeutic approach for the management of cancer. Targeting GLUT1 in cancer has been suggested using a variety of strategies. Utilizing GLUT1 inhibitors is one strategy since they can prevent the transfer of glucose into cancer cells and interfere with their energy consumption (Santra et al., 2020). For the treatment of cancer, numerous GLUT1 inhibitors are currently under clinical development after showing encouraging outcomes in preclinical research (Santra et al., 2020).

The use of glucose metabolism-based imaging methods, such as positron emission tomography (PET) with radiolabeled glucose analogs, to observe the levels of GLUT1 expression in tumors, is another strategy for targeting GLUT1 in cancer (Santra et al., 2020). The use of GLUT1-targeting medicines can be guided by the information these imaging techniques can provide on the level of GLUT1 expression in malignancies.

GLUT1 deficiency is a rare genetic disorder. It is caused by variants in the SLC2A1 gene. SLC2A1 provides instructions for producing GLUT1. In the brain, the GLUT1 protein is involved in moving glucose from the bloodstream into the cerebrospinal fluid (CSF), which surrounds the brain Chen, Chen, & Liu, 2013). Additional symptoms have been reported in individuals with Glut1 deficiency syndrome including mental confusion, lethargy, drowsiness (somnolence), repeated, abnormal, rapid eye and head movements in both horizontal and vertical directions, paralysis of one side of the body (hemiparesis), total body paralysis (Bazinet et al.,2014).

GLUT1 has been implicated in diabetes, cancer, as well as neurological conditions such stroke, traumatic brain injury, and Alzheimer's disease (Baker, Blass, & O'Hare, 2012 ; Chen et al., 2013; Li, Li, & Tang, 2014). It has been suggested that these illnesses emerge as a result of dysregulation of GLUT1, which is expressed in the brain and is in charge of the uptake of glucose by neurons. In animal models of stroke and traumatic brain damage, inhibition of GLUT1 has been demonstrated to enhance outcomes (Baker et al., 2012; Chen et al., 2013).

In people with epilepsy, the brain's GLUT1 expression is frequently decreased, which results in decreased glucose uptake and utilization (Bazinet et al., 2014). In those with epilepsy, this decrease in glucose metabolism has been related to the onset of seizures and other neurological symptoms (Bazinet et al., 2014).

Reduced GLUT1 expression has been connected to the emergence of cognitive impairments in Alzheimer's disease, as aberrant GLUT1 expression has been seen in the brains of those with the condition (Winkler, Nishida, Sagare,

1.INTRODUCTION:

Glucose is a primary source of energy for cells in the body, and the uptake and utilization of glucose is regulated by a complex network of proteins which called glucose transporters (Hantzidiamantis & Lappin, 2022). Sodium-glucose co-transporters and glucose-mediated transporters (GLUTs) are the two categories of glucose transporters (Scheepers, Joost, & Schurmann, 2004). The glucose transporter family consists of fourteen members (Augustin & Mayoux, 2014). Different tissues produce GLUT differently and it works across the plasma membrane in the direction of the glucose gradient (Wilson-O'Brien, Patron, & Rogers, 2010). Class I, II, and III are the three subclasses that make up the GLUT family. High-affinity GLUT1, low-affinity GLUT3, GLUT4, GLUT14, and GLUT2 are all members of type I (Byers, Howard, & Wang, 2017). GLUT5, GLUT7, GLUT9, and GLUT11 are class II transporters with very low affinity for glucose. The class III transporters are GLUT6, GLUT8, GLUT10, and GLUT12 (formerly known as GLUT-X1). Sodium-glucose co-transporters move glucose in opposition to its gradient of concentration (Wright, Hirayama, & Loo, 2007).

GLUT1 plays a crucial role in glucose homeostasis (Palacin, Estevez, Bertran, Zorzano & Marsol,1998) and expressed in many tissues in the body, including the brain, muscles, and red blood cells, and it is regulated by a variety of factors including insulin, glucose levels, and substrate availability (Wang, Wang, Shen, & Zhang, 2016). GLUT1 is encoded on the short arm of chromosome 11 and is synthesized in the endoplasmic reticulum (Wilcox, 2005). Dysregulation of GLUT1 has been linked to a variety of diseases, including diabetes, cancer, and neurological disorders, making it a potential target for therapeutic intervention (Vulturar, Chiş, Pintilie, Farcaş, Botezatu, Login, Sitar-Taut, et.al. 2022)

While GLUT1 is essential for normal physiological function, dysregulation of GLUT1 has been implicated in a number of diseases. For example, abnormal expression of GLUT1 has been observed in cancer cells, and targeting GLUT1 has been proposed as a potential therapeutic strategy for cancer treatment (Santra et al., 2020). In addition, GLUT1 has been implicated in neurological disorders such as epilepsy and Alzheimer's disease (Bazinet, Al-Haidari, Bains, & Wurtman, 2014 ; Lu et al., 2015). Dysregulation of GLUT1 has also been linked to cardiovascular disease, as reduced GLUT1 expression has been observed in the endothelial cells of individuals with atherosclerosis (Iwamoto, Tamura, & Kataoka, 2020).

In this review, I will discuss the role of GLUT1 in these diseases and the potential for targeting GLUT1 as a therapeutic strategy. We will also consider the current state of the literature on GLUT1 in these diseases and highlight areas for future research.

The research aiming to clarify the effect of GLUT-1 in cases of health and diseases and study the drawbacks and benefits of its uses in different diseases.

2.METHODS:

Focusing on the significance of GLUT1 in the etiology of diseases and potential therapeutic approaches, a thorough assessment of the literature was carried out primarily utilizing Google Scholar and PubMed databases. These diseases include diabetes, cardiovascular illness, neurological conditions, and cancer. Search terms included GLUT1, glucose transporter, cancer, neurological problems, cardiovascular disease, and therapeutic approach. The search was restricted to recent English-language publications.

3.RESULTS AND DISCUSSION:

High blood glucose levels are the hallmark of the chronic condition known as diabetes. GLUT1 has been identified as a possible therapeutic target for the management of diabetes. The expression of GLUT1 in the pancreatic beta cells that produce insulin has been connected to the emergence of type 2 diabetes (Zhou, Qi, & Zhang, 2011). In animal models of type 1 diabetes, inhibition of GLUT1 has been found to increase insulin

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بحث مرجعي

ناقل الغلوكوز-1 في الصحة والمرض

سعيد عوض القحطاني

(قدم للنشر في 1444/6/9؛ وقبل للنشر في 1444/11/11هـ)

مستخلص البحث: ناقل الغلوكوز-1 هو بروتين مسؤول عن نقل الغلوكوز من الدم إلى الخلايا. وتواجد في كثير من خلايا الأنسجة في جسم الإنسان، بما في ذلك الدماغ والعضلات وخلايا الدم الحمراء. هذا الناقل له علاقة في حدوث عدد من الأمراض ، بما في ذلك مرض السكري والسرطان والاضطرابات العصبية والأمراض القلبية الدموية. حيث وجدت الدراسة ارتباطه باضطراب خلايا بيتا البنكرياس التي تنتج الأنسولين بمرض السكري من النوع الثاني. كما تم ربطه عند اختلاله بنمو الخلايا السرطانية وتكاثرها فضلا عن الحالات العصبية مثل الصرع ومرض الزهايمر. لذلك تجدر الاشارة الى ان دراسة مثل هذا الناقل بشكل مكثف لمعرفة كيف كيف يساهم في حدوث بعض الأمراض سببا لمعرفة كيفية العلاج المحتملة.

كلمات مفتاحية: ناقل الغلوكوز-1، داء السكرى، السرطان، اضطرابات عصبية، التدخل العلاجى.

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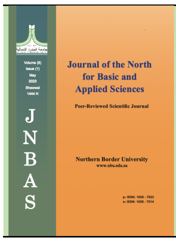

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Review Article

Glucose Transporter 1 in Health and Disease

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Abstract: Glucose transporter 1 (GLUT1) is a protein that is responsible for the transport of glucose from the bloodstream into cells. It is found in the cell membranes of many tissues in the body, including the brain, muscles, and red blood cells. Dysregulation of GLUT1 function has been implicated in several diseases, including cancer, neurological disorders, and cardiovascular disease. In this review, we will discuss the role of GLUT1 in these diseases and the potential for targeting GLUT1 as a therapeutic strategy.

Key words: glucose transporter 1, GLUT1, diabetes, cancer, neurological disorders, therapeutic intervention

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4. CONCLUSION

The vertical integration of basic science and clinical practice requires an understanding of anatomy. Cadaveric dissection and evaluation of prosecuted specimens are two common pedagogies. Many educational breakthroughs are on the horizon that will have an impact on anatomy education in the future. Using interactive online multimedia as a comprehensive self-paced substitute for didactic lectures to assist students to prepare for practical classes is one example. Teaching and learning materials are inextricably linked. With the right application of the former, the latter can be transformed. Teachers will not be replaced by interactive multimedia, but they will be able to avoid getting drained (and thus burnt out) by addressing much of the theory that would otherwise result in a large lecture load. This would free up time for lectures that teach principles and practical classes (preferably dissections with clinical procedures) that include the active discovery of their implications and applications

The role of regulatory bodies/councils like national medical councils can be instrumental in promoting the Anatomy, e.g., as per the laws of the Pakistan Medical & Dental Council medical colleges have been provided with a minimum number of must-have faculty for 50, 100 and so on students, in an institute.

Although Medical education is worst if treated as a business is a bitter reality that there is a global growth of medical institutes in the recent past decade or so. The subject has never been a career choice but for a few. This trend was noted worldwide as monetary benefits are of paramount importance in today's mechanized world and, as they say, money makes the mare go. If regulated properly this can be good for the new lucrative jobs that can be created in this section of medicine which has long been neglected and despite its importance not given the deserved respect.

5. CONFLICT OF INTEREST

The author declares no conflict of interest whatsoever.

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enter them. As a result, creating efficient teaching techniques for anatomy is critical for safe medical practice. For hundreds of years, cadaver-based instruction has been the primary teaching instrument; nevertheless, opinions differ on whether full corpse dissection is still acceptable for current undergraduate education. Many medical schools have abandoned costly and time-consuming dissection-based instruction in favor of alternative methods of instruction such as prosection, medical imaging, living anatomy, and multimedia resources due to a lack of curricular time, trained anatomy faculty, and resources for gross anatomy courses in integrated or/and system-based curricula (Estai & Bunt, 2016). There is an urgent need of bringing morphological findings closer to practical medicine concerns, especially crucial during the reform of the healthcare system in any part of the world (Mel'man & Shutka, 1988).

A person who examines disease origins and effects, frequently using bodies to diagnose illness or determine the reason for death is for sure going to be a good clinical practitioner.

Evolution is a long-term process, and only those who are able to alter "survive." The COVID-19 pandemic has completely transformed modes of anatomy instruction. "Should dissection be included in the medical school curriculum or not?" proved to be a hot debate among the anatomy community, and the pandemic presented a forced opportunity to investigate the "*cadaverless*" anatomy education scenario around the world. During the crisis, anatomists did turn to the many virtual platforms available to investigate new technologies, teaching approaches, and evaluation methodologies as quickly as possible. Over the years, this subject has also evolved from a single subject to a combination of various subjects. Hence, every aspect has changed, from cadaver procurement, embalming, and preservation to curriculum, literature, teaching techniques, and examinations. A growing number of medical students, restricted resources allocated for the subject by the institutes, and less time given to the subject in the new curriculum have forced every anatomist to learn new procedures. Anatomy has been evolving since its inception but more rapidly over the last two decades (Singal, 2022).

During the COVID-19 lockdown, distance learning (DL) in many subjects has been granted and it has been found that connecting the DL-precepts framework with individual domains of the key learning outcomes framework, has proved beneficial for imparting the core knowledge (Naidoo, Azar, Khamis, Gholami, Lindsbro, Alsheikh-Ali & Banerjee, 2021).

A higher education paradox is the reduction of academic posts in higher education and the increase in graduate entrance rates. PHT (planned happenstance theory) is a professional development concept that emphasizes positive outcomes from uncontrollable pre-career experiences. PHT-based educational techniques emphasize that graduates with fresh metacognitive skills can pursue new job pathways (Bazos, Attardi, Baytor & Wilson, 2021).

It is important to remember that the potential for developing new instructional tools to give the greatest anatomy education is limitless given the current availability of animation tools and software that can simulate a virtual world. It's the right time to blend traditional anatomical instruction with innovation, which requires modern anatomists to work with both traditional and tech-savvy scientists. This will not only enhance the appeal of a subject but will generate more interest in today's *technophile* students. Anatomy is the only 3D subject that is taught in the preclinical years and we anatomists shall use this tech boom for our use and survival. In a very interesting study done on medical students in India in 2004 with a focus on anatomy as a subject and career, the majority of the respondents agreed that Anatomy was a basic pillar for being good physicians. However, the percentage of responses for taking up the subject as a career was moderate, the majority thought that they would take it up as a career if better research facilities are provided (Anand, Raibagkar &Ghediya, 2004).

The well-known saying of Tiedemann Heidelberg, 1781–1861, a pioneer German Anatomist and Physician of his period;

“Doctors without anatomy are like moles.
They work in the dark and the work of their hands are mounds.”

It still seems applicable even after more than two and a half centuries (https://www.ub.unibelieved that incorporating a patient-centered or case-based curriculum will reinforce basic science principles. One disadvantage is that cadaveric dissection hours in the gross anatomy laboratory are reduced. Limited anatomical exposure leaves knowledge gaps in those entering the surgical profession, which shall be or has to be remedied during residency training (Heisler, 2011).

A paradox has been observed in anatomy teaching as the amount of content and knowledge about anatomy has grown, while the number of hours allotted for topic instruction has shrunk. This factor may and can stress the use of time-saving and effective educational tools. There is no single academic strategy or prototype in anatomy teaching that has been proven to be superior to another (Moro, Štromberga, Raikos & Stirling, 2017). However, four suggested strategies found in the literature could be:

1. Cadaveric dissection is a fantastic anatomy learning tool, but it necessitates a lot of resources, infrastructure, and time. Prosections and plastinated specimens, which are real human specimens, should be the second choice, followed by three-dimensional interactive dissection tables, which allow students to explore life-size anatomy, and other learning modalities (Ghosh, 2017).
2. Cutting-edge technology can be effectively used to study the subject's complicated principles and to enhance passive lectures.
3. Active learning approaches such as problem-based learning, computer-assisted learning, and case studies may be used in the classroom (Papa & Vaccarezza, 2013).
4. If cadaveric dissection resources are limited, anatomy and surgery postgraduate students or residents may be given priority in using these materials.

With the advent and advancement of a new technique termed '*Omics*' technology, the scope of the subject has now expanded to cover genetic illnesses (Bhattacharjee, Ceri, Holland, Holmes, Kilroy, McGonnell & Reynolds, 2021). This also helps to bury the stigma that anatomy is not a science because it is not a research-driven discipline.

Similar problems have been found in Pakistan, where approximately a decade ago, anatomy was stressed as a core basic element within a typical medical science curriculum in all medical and dentistry universities. Now that schools are embracing problem-based learning (PBL) teaching philosophies, the techniques and extent of anatomy education shall be hotly debated since medical colleges in Pakistan has introduced a PBL curriculum that exposes the basic sciences largely in clinical contexts. PBL curriculum, it is believed, dilutes basic science teaching, particularly anatomy (Memon, 2009).

In a study, it was found that the dissection group had much higher post-course exam results. These findings got challenged when the course duration was changed. There is no compelling evidence that one method is preferable to the other when it comes to teaching surgical anatomy. According to learner surveys, dissection does improve the learning experience (Koh, Yeow, Srinivasa, Ng, Ponnamperuma & Chong, 2021). Many times successful surgeons are the ones who had been enthusiastic dissectors in their student years. With the use of newer techniques and methods, anatomy teaching can be turned into an interpretive process rather than a purely descriptive one. This can result in more efficient use of expertise, which is likely to be more enjoyable for both teacher and student.(Eizenberg, 2015, Eizenberg and Briggs & Barker, 2014).

There is a need to create a postgraduate Anatomical Sciences degree program in response to the expanding usage of online education resources and the growing demand for anatomical education from non-traditional student cohorts (Alethea, Kelsey, McCulloch, Gillingwater, Findlater, Jennifer & Paxton, 2020).

There is a lot of discussion about the best ways to communicate anatomical knowledge. For safe clinical treatments, competent clinicians, particularly surgeons, require a thorough understanding of anatomy. However, because students have had such minimal exposure to anatomy throughout clinical training, there is concern that medical students will be unprepared for clerkships and residency programs when they categories, then there is the developmental, neurological, and microscopic study of form and structure and not to forget the latest addition to it; the clinical anatomy. In a 2019 study conducted in Abraka, Nigeria, to view anatomy as a career option, it was found that medical students do like anatomy as a course, but interest in anatomy as a career option was found to be low (Oladunni, Emmanuel, Jonathan & Okoh-Uku, 2019).

Anatomy has long been a foundational course in medical education, regardless of country or specialty. Its only pedagogy till recently was dissection and didactic lectures. To further consolidate and enrich the learning experience, the teaching style has been revolutionized with a greater focus on models, imagery, simulation, and the internet. The high cost of not focusing on adequate anatomy education would inevitably result in unskilled anatomists and healthcare workers, putting patients at risk (Sugand, Abrahams & Khurana, 2010).

In Australia and New Zealand where medical schools have decreased the Anatomy teaching hours dramatically in recent years, it was found that the curriculum content, instruction approach, and assessment differed greatly amongst institutions as there is no national curriculum for anatomy training. Such variation in anatomy education and assessment raises a crucial question: Do the graduates of different medical programs have or will have varying levels of mastery of anatomy? (Craig, Tait, Boers & McAndrew, 2010).

As elaborated, understanding human developmental anatomy is essential for accurately diagnosing and treating patients with congenital clinical entities. Therefore, the importance of developmental anatomy in the medical curriculum merits careful consideration. The Educational Affairs Committee of the American Association of Clinical Anatomists (AACA) designed a clinical anatomy curriculum in developmental anatomy in order to provide help in establishing an undergraduate medical curriculum that adequately handles developmental anatomy, for the institutes that believe in promoting the subject as a specialty. It covers the topics and principles that will enable physicians to not only diagnose and treat congenital illnesses but also to provide a firm foundation for future discoveries, particularly in the rapidly growing field of molecular developmental anatomy. It may also ensure that all medical students receive methodical training in developmental anatomy and that each student, regardless of the institution attended, is exposed to a curriculum that will provide him or her with the necessary competence and confidence to practice medicine effectively in the twenty-first century (AACA, 2000).

There is widespread agreement that the number of contact hours of this fundamental discipline in a packed college curriculum is steadily decreasing. The same might be said for postgraduate specializations in which surgical anatomy is crucial. Patient safety is going to be harmed in the long run as a result of this lack of appropriate anatomical information. A content and extent reduction policy in most medical schools have had and continues to have, a significant impact on anatomy directly and hence the quality of the medical graduates produced, indirectly. A rise in medico-legal claims has also been linked to poor anatomy knowledge. Surgical anatomy courses at the postgraduate level and the restoration of dissection courses at both levels could all be steps in the right way to transform the current situation (Yammine, 2014).

According to some doctors, the least amount of anatomy is required for clinical practice. This saga creates interpretational difficulties for anatomical distortions or structural changes that affect organ and system functions. An interwoven inter-relationship among Anatomy, Physiology, Pathology, Radiology and clinical sciences is essential and required for accurate diagnosis and treatment analysis. This augments what has been reported in the literature that lacking understanding of anatomy often leads to very low clinical practice comprehension as Anatomy is 'most vital' for clinical practice (Singh, Yadav, Pandey &, Jones, 2022). To overcome this synopsis inclusion of a system-based approach to anatomy training in a medical school curriculum can spark a transformation (Reeves, Sheedlo & Roque, 2005).

At the outset of the twentieth century, medical education became more standardized and remained rather consistent until recently. It is

1. INTRODUCTION

Anatomy is deemed the oldest scientific discipline of medicine. The first documented scientific dissections on the human body were carried out as early as the third century B.C. in Alexandria (Ghosh, 2015). At that time, anatomists used to explore internal mysteries of human structure through dissections of animals, primarily pigs, and monkeys. The quest and curiosity to know about the human machine are as old as humanity itself. In 1762, France was the first country to establish veterinary medicine as a scientific discipline and that led to the evolution of human anatomy. That may be a reason that Anatomic models constructed and transmitted over the world by the French physician Louis Thomas Jerôme Auzoux (1797-1880) at the turn of the nineteenth century were perhaps the most fascinating ones, made by a technique called "papier-mâché" meaning chewed paper in French (Ortug & Yuzbasioglu, 2019). In 1842, the first Ottoman-Turkish veterinary school was formed, largely to develop and care for army horses (Ortug, Uluışık & Ortug, 2021).

In a medical curriculum, anatomy and surgery are the only visual or 3D subjects (Prentice, 2005), hence we can rightly term Anatomy as the mother of surgery and other medical sciences.

With the dawn of the 21st century and the rapid population boom of the planet, there has been a mushroom growth of medical schools and colleges all over the planet. This has materialized in the creation of a lot of new job opportunities for fresh graduates not only in clinical sciences but basic sciences too.

Sadly, Anatomy had never been a preferred choice as a career for fresh graduates, reasons for which we shall try to find out in this review and how the subject itself has been treated by clinicians, academia, and students over time. Still, the importance of this subject cannot be minimized despite many manipulations with the curriculum all over the world.

Anatomy as an area of medicine has infiltrated so many fields, and as a result, it is cardinal to consider while making a professional choice. We are continuously learning more about anatomy every day, despite the fact that it has been practiced for thousands of years. Anatomists are continually discovering new structures whether microscopic or macroscopic particularly about humanly body structure (Stanford, Rutland, Sturrock & Rutland, 2020).

This paper will try to find out the shortcomings, and variations suffered by the subject and may be able to provide a clue why is such an important subject cannot be a career choice for fresh graduates. The paper seems the first from the Arab world to focus on this important topic as no previous literature showed that such work has been done before in the region.

2. MATERIAL & METHODS.

A review of the online available literature for a period of last more than two decades was done. Only the articles that were pertaining to the subject of anatomy were chosen. Topics selected were prioritized as per the anatomy as subject and career. An effort was made to collect the papers from varied contents and regions so the evidence gathered could hold a universal appeal.

3. DISCUSSION

Whilst it has been argued that many areas of basic science will change over the course of a doctor's professional life, precluding their inclusion in a ‘core curriculum’; gross human anatomy will certainly remain constant. Anatomical knowledge backs the examination of a patient, the formation of a diagnosis, and the communication of these findings to the patient and other medical professionals. It provides a platform of knowledge common and suitable to all medical careers (Turney, 2007). Anatomy always has been a cornerstone of medical education for hundreds of years and it is proclaimed that it has survived the most demanding pedagogic test – *time*. However, in recent years, there have been efforts to slowly squeeze the human anatomy from the medical curriculum. Although this limitation of the subject is being argued, discussed, and planned the world over.

Digging rationally, anatomy is not a single subject but a fusion of subjects ranging from gross anatomy dividing further into general and special

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بحث مرجعي

علم التشريح تم اختياره عبر الزمن كتخصص ولكنه خيار مهنى مهجور

واجد على شتا*

(قدم للنشر في 1444/4/7؛ وقبل للنشر في 1444/8/1هـ)

مستخلص البحث: علم التشريح قديم قدم الإنسانية نفسها. أدى فضول التعرف على الجسم إلى تطور النمو وتنويع علم التشريح بمرور الوقت. نما الموضوع من دراسة التركيب البشري ليشمل مجالات علم المناعة وعلم التشريح المجهري.
على الرغم من نمو علم التشريح من موضوع دراسى واحد إلى دمج العديد من الموضوعات الدراسية على مر السنين ، فقد فشل تنوعه في جذب المهنيين الطبيين للانضمام إليه واعتماده كمهنة. تم إجراء مراجعة للأدبيات التي تعود إلى ثلاثة عقود تقريبًا في محاولة لمعرفة التحولات التي واجهها هذا الموضوع. لقد صمد الموضوع أمام اختبار الزمن ومؤخراً خلال جائحة **Covid-19**الأخير ، حيث كان أحد الموضوعات التي يمكن توصيلها بكفاءة للطلاب بطريقة ذكية باستخدام التقنيات الحديثة والرسوم المتحركة.
على الرغم من أهميته الخطيرة ، يتم التلاعب بالموضوع حسب الرغبة من قبل المعاهد الطبية في جميع أنحاء العالم. يحدث هذا في غياب مدخلات من الكليات وعلى حساب تخصيص وقتها ومساحتها لمواضيع أخرى من العلوم الطبية. تمت مناقشته في أنه لا يمكن لأي طبيب أن يدعي إتقان الطب دون أن يكون لديه معرفة عملية مناسبة بالتشريح. هناك حاجة إلى منهج موحد للتشريح على الأقل على المستويات الوطنية. يمكن للجمعيات التشريحية والهيئات التنظيمية في البلدان أن تلعب دورًا إيجابيًا لمنع تدهور موضوع يعد أحد اللبنات الأساسية للعلوم الطبية.

كلمات مفتاحية: علم التشريح، موضوع دراسي، مسار مهنى، كوفيد-19 ، جزء من التكنولوجيا الحيوية، منهاج دراسى، ثلاثى الابعاد.

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REVIEW ARTICLE

Anatomy As A Time Tested Speciality but A Forsaken Career Choice

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Abstract: Anatomy is as old as humanity itself. The curiosity to learn about the body has led to the growth evolution and diversification of anatomy over time. The subject has grown from a study of human structure to encompass the fields of immunology and microanatomy.

Although anatomy has grown from a single subject to a combination of many subjects over the years, its diversification has failed to attract medical professionals to join it and take it up as a career. A review of the literature of around three decades was done in an effort to see what transitions the subject has faced. The subject has stood the test of time and more recently during the recent Covid-19 pandemic, where it was one of the subjects that could be efficiently communicated to the students in a smart way making use of modern technologies and animation.

Despite its grave importance, the subject is being manipulated at will by the medical institutes world over. This is happening in the absence of input from the faculties and at the expense of the allocation of its time and space to other subjects of the medical sciences. It is debated that no physician can claim mastery of medicine without having a proper working knowledge of anatomy. There is a need for a uniform curriculum of anatomy at least at the national level. Anatomical associations and regulatory bodies of the countries can play a positive role to prevent the decline of a subject that is one of the building blocks of medical sciences.

Keywords: Anatomy, Subject, Career, Covid-19, Omics, Curriculum, 3D.

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6. CONCLUSIONS AND RECOMMENDATIONS

This research investigated the causes of material waste generation in construction projects in the Northern Border Province of Saudi Arabia. A literature review and pilot study identified 21 material waste causes in construction projects. The explored causes were classified under six primary categories: (1) worker group, (2) design and documentation, (3) management, (4) procurement, (5) handling, and (6) external. The collected data were analyzed using the average index method, and causes were ranked according to their importance levels. The results identified the top five causes of material waste increase in construction projects as: damage to materials due to project failure and extensions, unskilled labor and technicians, improper material usage, design changes during construction, and poor implementation or failure to follow engineering and industrial principles. Unique causes of material waste generation have been identified through interviewing experts and then evaluated in this research, such as the damage to materials due to projects failure and extensions for long periods and failure to adhere to the quality control plan.

The results of this research show that worker-related causes are major contributors to waste generation. Technical staff and workers in contractor and subcontractor teams play a crucial role in decreasing waste in the implementation phase of projects. It is recommended that human resource management in companies hire well-trained labor and staff with sufficient knowledge and expertise to avoid rework during construction. Continuous education and training in engineering and industrial principles is encouraged to build workers and staff skills. In addition, companies should focus on increasing worker and staff awareness of waste management principles and applications. Design- and documentation-related causes are ranked as the second major contributor. Clients should provide a complete list of requirements before the design stage to avoid changes during construction. Designers must provide comprehensive and applicable designs to avoid errors and inconsistencies in design documents. Design and contractual documents, including technical specifications, should be revised by designers and contractors in the early stages of projects to minimize errors, complexity, and inconsistency.

The research results provide a general overview of the causes of material waste and their relative importance and will provide professionals in different project parties with a better understanding of the waste causes to develop a suitable minimization approach. Professionals in different phases of projects should address the identified and evaluated causes to develop effective waste management plans. Further studies are recommended to investigate the causes of material waste in specific types of construction projects by evaluating the significance of the differences in causes. Further research can be performed to evaluate current practices and develop appropriate waste management approaches to counter the causes of construction waste.

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5. DISCUSSION

Table 3 presents the results of the survey and the ranking of waste causes according to their importance levels using the average index method. The top-ranked cause of material waste increase in construction projects is damage to materials due to project failure and extensions, which are categorized in the management group with $AI = 4.44$. The causes of delays in projects that lead to time extensions should be identified and assessed by professionals to minimize or avoid their impact. The top causes of delays in public construction projects, according to the literature, include awarding projects to the lowest bidder, awarding contractor projects beyond their financial and technical potential, late procurement of materials, late delivery of materials, and delay in progress payments (Alsuliman, 2019; Abdellatif & Alshibani, 2019).

The results in Table 4 show that worker-related causes are major contributors to material waste generation. Unskilled labor and technicians, improper material usage, and poor implementation or failure to follow engineering and industrial principles are the top three causes in this group. These three causes are also ranked in the top five overall causes in Table 3, which shows the essential impact of workers on material waste generation. All worker-related causes are significant based on consultant perspectives, as shown in Fig. 2. Worker-related causes were also categorized as important in two other studies (Gopang & Latif, 2021; Al-Rifai & Amoudi, 2016). Lack of experience, poor workmanship, and inappropriate use of materials are ranked as the top causes of material waste in transportation projects (Gopang & Latif, 2021). Furthermore, the lack of skilled workers and subcontractors, and rework required because of worker error were the top two ranked causes of waste in Jordan (Al-Rifai & Amoudi, 2016). According to Nagapan *et al.* (2011), worker-related causes, such as worker mistakes and a lack of skills and training, are common causes of waste generation. Technical staff and workers in the contractor and subcontractor teams play a crucial role in decreasing waste in the implementation phase of projects. According to Luangcharoenrat *et al.* (2019), technical staff and workers should be willing to change their attitudes and behaviors to achieve successful construction waste management and minimization. Continuous education and training of engineering and industrial principles are essential to minimize worker-related causes of waste generation and to build worker and staff skills.

Design- and documentation-related causes are ranked as the second major contributor, as shown in Table 4. Design changes during construction and designers' weakness in writing effective material technical specifications are the top two causes in this category and are also ranked fourth and sixth among all investigated causes shown in Table 3, highlighting their importance. The top factors from contractor perspectives, as shown in Fig. 3, identified three significant causes in the design group. Design- and documentation-related causes were also categorized as important causes in four other studies (Kaliannan *et al.*, 2018; Al-Hajj & Hamani, 2011; Latif *et al.*, 2020; Al-Rifai & Amoudi, 2016). According to Nagapan *et al.* (2011), frequent design changes are one of the most dominant reasons for increasing construction material waste. Additionally, it is estimated that 33% of construction waste is generated through design decisions (Osmani, Glass & Price, 2006). One of the main reasons behind design-related causes is designers' lack of knowledge and experience about construction techniques and methods, which causes errors and inconsistencies throughout the design process (Chandrakanthi, Hettiaratchi, Prado & Ruwanpura, 2002). Design and contractual documents, including technical specifications, should be revised in the early stages of projects by designers and contractors to minimize errors, complexity, and inconsistency.

The results presented in this study were limited to construction practices in public projects in the northern region of Saudi Arabia and did not include demolition practices. However, surveying in different regions of Saudi Arabia would give a better understanding of waste causes to further develop a suitable minimization approach. The sample of the study was limited to three project parties (owners, consultants, and contractors). Future studies could include designers and material suppliers.

indicate that the two most significant causes are related to workers in the contractor or subcontractor teams, i.e., unskilled labor and technicians, and poor implementation and failure to follow engineering and industrial principle'. The other two causes in the worker group are also the most significant based on consultant perspectives: improper material usage and lack of workers' awareness. The top causes based on consultant viewpoints included causes categorized in other groups, but four causes are also related to contractors and subcontractors: material ordering errors, failure to adhere to the quality control plan, non-compliance to the specifications, and inappropriate site storage.

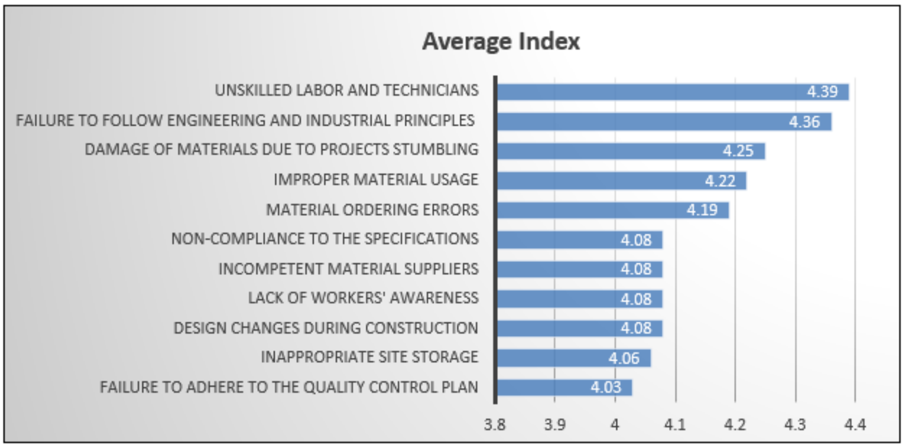

Figure 2. Top factors causing waste, based on consultant perspectives

The average index scores in Fig. 3 indicate the top causes of material waste in construction projects based on the contractor perspectives. The results show that damage to materials due to project failure and extensions for long periods is the most significant factor, which is also ranked first in the top overall causes in Table 3. Three causes from the design group are of significance based on contractor perspective, differing from the results in Fig. 2 as only 'design changes during construction' is significant based on consultants' point of view.

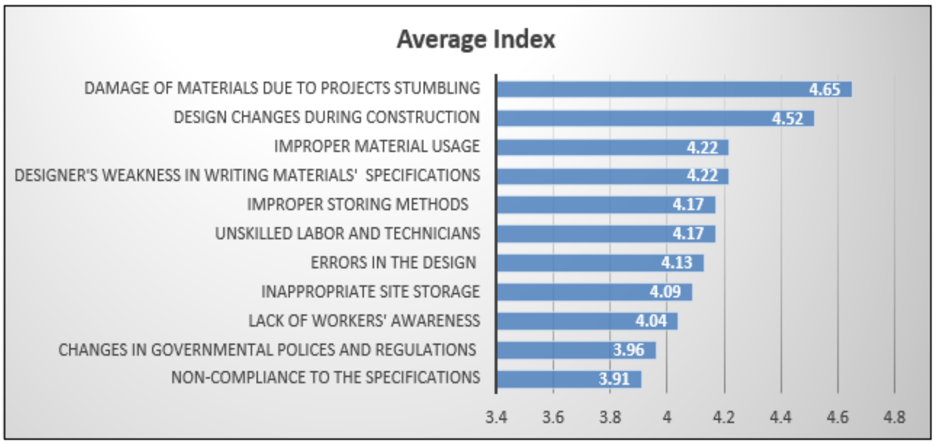

Figure 3. Top factors causing waste, based on contractor perspectives

Table 4. Mean Average Index (*AI*) and ranking of waste cause categories

Cause Category	*AI* Mean	Rank
Workers group	4.220	1
Design and Documentation group	4.047	2
Management group	4.035	3
Procurement group	3.933	4
Handling and External groups	3.805	5

4.3.1. Workers group

The *AI* and ranks of the four causes categorized in the worker group are listed in Table 3. The participants ranked 'unskilled labor and technicians' cause as the biggest contributor in this group in this group, with *AI* = 4.33. Unskilled labor and technicians in the contractor and subcontractor teams ranked second. Three out of four causes in the worker group are also ranked in the top five overall causes, which shows the essential impact of workers' causes on material waste generation.

4.3.2. Design and documentation group

The *AI* and ranks of the four causes categorized under the design and documentation groups are listed in Table 3. The participants ranked 'design changes during construction' as the most contributing cause in this group, with *AI* = 4.23. Design changes during construction ranked fourth in its effect, amongst all investigated causes, which shows its important effect on the materials waste generation in construction projects.

4.3.3. Management group

The *AI* and ranks of the four causes which are categorized in the management group are revealed in Table 3. The participants ranked 'damage of materials due to projects failure and extensions for long periods' as the most contributing cause for generating construction waste in this group, with *AI* = 4.44. This factor ranked first in its effect amongst all the causes, which shows its important effect on the materials waste generation in construction projects. However, the other three causes in this group ranked 11th, 13th, and 18th of the overall causes, showing they had less impact.

4.3.4. Procurement group

The procurement group ranked 'material ordering errors' as the biggest cause of waste generation in this group, with *AI* = 4.08 (Table 3). Material ordering errors ranked ninth in its effect among all investigated causes, which demonstrated its lesser effect compared to causes in other groups.

4.3.5. Handling and external groups

The handling and external groups had less of an impact than the other groups. The *AI* and ranks of the four causes categorized in the handling group are listed in Table 3. The participants ranked 'inappropriate site storage' as the biggest cause of waste, with *AI* = 4.08, which ranked eighth. The other three causes in the handling group and the causes in the external group had less effect.

4.4 Consultant and contractor perspectives on factors causing material waste

This section focus on consultants and contractors' perspectives on factors causing material waste to show the differences in in their perceptions. Consultants and contractors were the two main parties participating in this survey and are considered closest to actual implementation activities due to their regular presence on project sites.

The average index scores in Fig. 2 show the top causes of material waste in construction projects based on consultant perspectives. The results where 0 indicating that the survey has no reliability and 1 indicating that the survey is consistent for all variables (Reynold and Santos, 1999). However, the α value must have a score of at least 0.70 to determine that the scale is reliable (Nunnally, 1994). The causes assessed in the study had an overall α value of 0.952, indicating that the measurements of five-point scale had high reliability at the 5% level of significance. Therefore, the survey data are appropriate for further analysis.

4.3. Average Index analysis

Table 3 presents the results of the survey and ranking of causes according to their importance levels using the average index method. Table 3 shows the mean average index, standard deviation, and ranking of the waste causes categories. The top five causes of material waste increase are damage to materials owing to failure and extensions, unskilled labor and technicians, improper material usage, design changes during construction, and poor implementation or failure to follow engineering and industrial principles.

Table 3. Average Index (*AI*) and ranking of construction waste generation causes

Group	Cause Description	Average Index	SD	Rank
Design and Documentation	Design changes during construction	4.23	0.96	4
	Errors in the design	4.02	1.07	10
	Inconsistency or errors in contractual documentation	3.86	1.09	16
	Designer's weakness in writing materials' technical specifications with using words have more than one meaning	4.08	1.02	6
Management	Failure to adhere to the quality control plan	3.98	0.94	11
	Rejection of materials due to non-compliance to the specifications	3.97	1.13	13
	Damage of materials due to projects failure and extensions for long periods	4.44	0.88	1
	Non integration of material planning with construction schedule	3.75	0.97	18
Procurement	Material ordering errors	4.08	0.99	9
	Incorrect order quantity (over ordering) of material	3.83	1.11	17
	Incompetent material suppliers	3.89	1.03	14
Workers	Improper material usage	4.27	0.87	3
	Poor implementation and failure to follow engineering and industrial principles	4.20	1.03	5
	Unskilled labor and technicians	4.33	0.81	2
	Lack of workers' awareness	4.08	0.85	7
Handling	Inappropriate site storage	4.08	0.96	8
	Inadequate packaging	3.69	0.95	20
	Damages during transportation	3.47	1.09	21
	Improper storing methods	3.98	1.05	11
External	Changes in governmental policies and regulations	3.72	1.04	19
	Theft or vandalism of materials	3.89	1.15	15

$$Average\ Index\ (AI) = \frac{W1X1 + W2X2 + W3X3 + W4X4 + W5X5}{N}$$

where N = Total number of participants, W = the constant weighting given to each cause by respondents for severity, which ranged from 1 for none to 5 for extremely severe, and X= the number of response frequencies for each given weight.
The population of the survey was restricted to professionals in three project parties (projects owners, consultants, and contractors) who worked at governmental construction projects located in the Northern Borders region. A total of 90 questionnaire survey forms were distributed online to professionals in the specified population, and only 64 questionnaire forms were successfully received and used in this study resulting into (71%) return rate. This is considered to be a sufficient sample size as scholars normally agree that a sample size of 30 or more is adequate for drawing meaningful results and sufficient for statistical data analysis (Ott & Longnecker, 2015). Responses of participants who work at private projects or do not have experience in the region projects were excluded.

4. RESULTS

4.1. Demographic of the study

General information on the collected data included the demographic information of the study participants. They were asked about the project party for whom they worked, work position, years of experience, and academic qualifications. Demographic data of the participants are presented in Table 2. The majority of the participants were closely related to construction implementation activities. More than half of the participants worked with consultants who usually supervised the implementation of projects, and 36% worked with contractors. It was found that most of the respondents worked as field or supervisor engineers (61%), and 25% worked as project managers. All participants held a bachelor's degree or higher. The participants' years of experience were delineated as follows: 54% with 11-20 years; 34% with more than 20 years.

Table 2. Demographic data of participants

Project Party	**Percentage (%)**	**Work position**	**Percentage (%)**
Owners Consultants Contractors	8 56 36	Project Manager Field or Supervisor Engineer Planning Engineer Other Positions	25 61 6 8
Years of Experience	**Percentage (%)**	**Academic Qualifications**	**Percentage (%)**
Less than 5 5 - 10 11- 15 16 – 20 More than 20	6 6 21 33 34	Diploma or less Bachelor Degree Master Degree PhD	0 87 9 4

4.2. Reliability Analysis

Reliability analysis was performed prior conduction the analysis to assess the consistency and reliability of the survey. Cronbach's alpha is one of the most common techniques used in evaluating the reliability of surveys. The Cronbach's alpha value α ranges from 0 to 1, specific type of projects and to combine similar causes that have same meaning.

2- Interviews were conducted with five experienced professionals who have more than 20 years of experience in the construction industry and have at least 10 years of experience in the region's projects. The experts reviewed the identified list of causes from the literature to specify the relevancy of the causes to the region projects. The final list of causes included 17 causes as shown in Table 3. The experts added four extra causes that are related to the region and not provided in the literature which are:
   - Damage of materials due to projects failure and extensions for long periods
   - Designer's weakness in writing materials' technical specifications with using words have more than one meaning
   - Poor implementation and failure to follow engineering and industrial principles
   - Failure to adhere to the quality control plan

In the third stage of the research methodology, the identified causes were grouped into six clusters; workers group, design and documentation, management, procurement, handling, and external causes. To specify the categories of the material waste causes, six studies that identified the classification of waste causes based on different categories were utilized as shown in Table 1. These categories were found to be the most frequent categories used in the classification of causes of construction waste. Consequently, the author utilized the studies in Table 1 to classify the causes of construction waste based on the most frequent categories as shown in Table 3.

Table 1. The most used classification categories for causes of construction waste

Classification of Category/ No. of Study	1	2	3	4	5	6	Freq
Procurement	*	*	*		*	*	5
Handling	*	*	*	*	*		5
Management	*	*	*	*			4
Design and Documentation	*	*	*			*	4
Workers	*	*	*		*		4
External	*	*					2
1. (Nagapan *et al.*, 2011) 2. (Gopang & Latif, 2021) 3. (Latif et al 2020) 4. (Khaleel & Al-Zubaidy, 2018) 5. (Al-Hajj & Hamani, 2011) 6. (Luangcharoenrat *et al.*, 2019)							

A questionnaire survey was constructed for data collection and a pilot study was conducted with the five experts to evaluate the survey content, response time, and appropriateness of the questions. They also checked the translation accuracy of the survey from English to Arabic. The questionnaire survey was conducted in two sections. General information on the respondents was gathered in the first section. The second section included a list of material waste causes identified from the literature and interviews and included the evaluation criteria. The evaluation was conducted using the Likert-type scale. The participants were asked to rate each cause based on their perceptions according to the causes' degree of impact (severity) on the increase in material. A 5-point scale was used for the evaluation of the cause of waste. The severity of the causes was categorized as follows: none, low, moderate, severe, and extremely severe (on a 1-to-5-point scale). The average index formula was used to analyze the data to determine significance, as was adopted by Gopang *et al.* (2021) and Latif *et al.* (2020). The weighted average was calculated as follows:

In the Iraqi construction industry, construction waste-related issues, such as increases in project costs and illegal landfill disposal, negatively affect the industry, with less priority given to waste management and minimization systems, which leads to increased annual construction waste (Khaleel & Al-Zubaidy, 2018). The study investigated the effects of 15 causes and categorized them into four groups: material handling, transportation and storage, on-site material management, and site management and practices. Construction engineers assessed these causes through a questionnaire survey and analyzed the data using the Relative Importance Indices (RII). The research findings concluded that the double handling of materials, damage of materials on site, and unskilled contractor technical workers were the most important causes in each category. Al-Rifai and Amoudi (2016) selected from the literature thirty-nine causes of material waste in the Jordanian construction industry and surveyed construction professionals through semi-structured interviews. Material waste was identified and grouped into two main categories: workforce-related and management-related factors. The most significant causes were lack of skilled workers and subcontractors, rework required because of workers' errors, lack of a quality management system, design changes, and changed orders during the construction stage.

In summary, studies have identified and assessed the causes contributing to construction waste generation in different countries in the Middle East. Only one study focused on transportation projects (Metro), while other studies investigated the causes of waste in general construction practices. Four studies utilized questionnaire surveys in the data collection process and analyzed the data using similar calculations, and only one study collected data using semi-structured interviews. Various causes of construction waste were identified in all studies; however, rework, lack of experience, and design changes were frequently identified as the top causes of construction material waste.

The construction industry in Saudi Arabia generates large amounts of construction material waste annually, and only one study has investigated this issue in a specific type of construction in the context of the Saudi industry. However, the causes of material waste were not investigated in general practices in the Saudi industry, as that study focused on the causes of construction waste in transportation projects (Metro) in Riyadh. In the northern region of Saudi Arabia, the causes of material waste have not yet been investigated by researchers, and the present study was aimed to identify influential material waste causes in construction projects in that region.

3. RESEARCH METHODOLOGY

The main objective of this research is to investigate the causes leading to material waste generation in construction projects in the Northern Province of Saudi Arabia. This study investigated the causes of material waste in construction practices in governmental projects. The main stages of the research methodology are shown in figure 1.

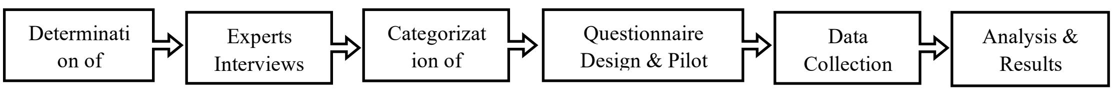

Figure 1. Research methodology stages

The first and second steps of the research methodology were implemented to identify material waste causes that will be assessed in the study through the following steps:

1- A comprehensive list of causes were identified through the review of the studies identified in the literature section. The list of causes were cross referenced and reduced to exclude causes that are only suitable for and time overruns in projects resulting from undesired activities that can cause physical waste, such as unnecessary movement of workers or materials, overproduction, rework, and waiting time (Nagapan *et al.*, 2012; Memon, Abdul-Rahman & Memon, 2014). Furthermore, inefficiency in the construction process can lead to nonphysical waste owing to the overuse of materials, equipment, money, and workers (Ma, 2011).

Various studies have identified and assessed the causes of construction waste generation in a global context. A study determined the root causes of construction waste generation through an extensive literature review, questionnaire survey, and practitioner validation (Kaliannan, Nagapan, Sohu, & Jhatial, 2018). The results identified five main root causes of material waste in construction projects: design changes, poor handling of materials, incorrect storage of materials, errors while ordering from suppliers, and the impact of weather. Researchers recommend that practitioners mitigate these five causes of waste management plans. Another study reviewed the global literature and classified causes into seven groups: design, worker, handling, site condition, management, procurement, and external effects (Nagapan, Rahman, & Asmi, 2011). These findings indicate that frequent design changes are the most common cause of construction waste generation. Semi-structured interviews were conducted to study waste management in Australia (Newaz, Davis, Sher & Simon, 2022). and found that the key causes included experience and training of site operators, knowledge, potential for onsite sorting, and identification of the economic value of diverted material. These factors are considered important for waste management plans.

In the Middle East, several studies have identified and assessed the causes of construction waste generation in different countries. One study on the Saudi construction industry (Gopang & Latif, 2021) focused on the causes of waste in a public transport project (Riyadh Metro), which consisted of six train lines and 85 stations with a total length of 176 km. The causes were grouped into six clusters: design, construction management, construction site conditions, construction material procurement, construction material handling, and external causes. The study surveyed 118 construction professionals working on metro projects and analyzed the data using the average index and factor analysis. The study identified that the top five causes of construction waste were rework, lack of experience, lack of a management plan, poor workmanship, and incorrect material storage. Additionally, causes analysis was applied using the Exploratory Factor Analysis (EFA) method to the top 15 causes. Five causes responsible for the construction waste were identified: workers' issues, management, improper handling, material-related issues, and design.

Al-Hajj & Hamani (2011) interviewed and surveyed professionals from medium and large construction companies in the United Arab Emirates (UAE) to identify and assess the causes of material waste in construction projects. The study analyzed data through the calculation of weighted average values and standard deviation. They identified that the top direct causes of material waste in UAE construction sites were poor design, resulting in excessive off-cuts, workers' lack of awareness, and rework and variations. In contrast, the top indirect cause of material waste was the lack of legal and contractual incentive. The researchers identified the most frequent measures which decreased the amount of construction waste as adequate storage, staff training, and delivery of materials just prior to their need on site.

In Oman, a study was implemented to identify different causes leading to material waste in construction projects at Muscat and Nizwa cities (Latif, 2020). A structured questionnaire was used to evaluate the perceptions of professionals working with consultants, clients, and contractors. Construction waste causes were grouped into six major categories in the questionnaire: handling, design, workers, procurement, management, and site conditions. The average index method used for analysis concluded that the most significant causes in each category were incorrect material storage, frequent design changes, worker's mistakes during construction, errors in quantity surveys, poor supervision, and poor site conditions.

1. INTRODUCTION

The construction industry contributes to environmental degradation and is considered one of the major producers of material waste. Worldwide, the construction industry uses 36% of produced energy, is responsible for 37% of released carbon dioxide due to construction activates into the Earth's atmosphere (UN Environment, 2021). Furthermore, natural resources decreases with construction activates, as the construction industry is the largest consumer of raw materials (UN Environment, 2021). Construction activities also negatively impact the environment by producing large amounts of waste material. Luangcharoenrat, Intrachooto, Peansupap & Sutthinarakorn (2019) compared several studies and identified that construction waste in 13 developed countries was responsible for 13% to 60% of waste in landfills.

In the Gulf region, the Gulf Cooperation Countries (GCC) are classified usually in the top 10% of countries with the highest waste production per capita in the world, (Kabir *et al*., 2013). It is estimated that approximately 120 million tons of construction and demolition (C&D) waste is produced annually by GCC (Ouda, Peterson, Rehan, Sadef, Alghazo, & Nizami, 2018). In the Kingdom of Saudi Arabia, one of the main sources of solid waste is the C&D activity. The increase in the country's population growth rate and urbanization levels has led to the rapid development of construction projects that significantly add to waste (Ouda *et al*., 2018). For example, 4.5–6.35 million tons of C&D waste are produced annually in Jeddah city, which has 14% of the country's total population (Alzaydi, 2014). In the Eastern Province of Saudi Arabia, 81 construction companies were studied by Ouda *et al*. (2018), who found that 86.4% of construction and demolition waste was landfilled annually and only 13.6% reused or recycled.

Identifying the causes and relative impact of waste is essential for developing effective waste management strategies. Adopting and applying these strategies in construction projects leads to waste reduction and brings many benefits, including the reduction of construction and disposal costs by minimizing the amount of wasted construction material, and the conservation of natural resources (Ling & Lim, 2002). The relationship between the causes of cost overruns and those of material waste were compared by Saidu & Winston, (2016), and the results showed that all incidents of material waste cause cost overruns in construction projects. The study concluded that effective application of waste management would result in a reduction in project costs. The reduction of carbon dioxide emissions (CO_2) is another benefit of reducing waste, while maintaining the health of laborers and nearby communities and increasing the longevity of landfill sites (Lingard, Graham, & Smithers, (2000). In addition, waste minimization provides a competitive advantage for all involved companies by improving overall performance and quality (Luangcharoenrat *et al*., 2019). Furthermore, the application of waste minimization processes promotes workforce productivity and skills, and enhances social, environmental, and economic sustainability (Al-Rifai & Amoudi, 2016).

2. LITERATURE REVIEW

The identification and classification of waste composition in the construction industry are essential for identifying causative factors and for effectively managing these wastes. Generally, the waste generated by C&D activities can be classified into two main groups: physical and nonphysical waste (Saidu & Winston, 2016). Physical waste is directly referred to as the solid waste resulting from activities such as building, roadwork, and demolition. Examples of solid waste include brick, steel, sand, tiles, glass, paper, blocks, wood, plastics, and concrete (Nagapan, Abdul-Rahman, Asmi & Hameed, 2012). In the EU, construction waste is divided into different categories: concrete, brick, tile, ceramic, asphalt, coal, wood, plastic, glass, metals, materials containing asbestos, insulation materials, rocks, soils, soils obtained from dredging, waste containing gypsum, and 'other' (Waste Thesaurus, 2015). This type of waste results in a complete loss of material and is regularly removed from construction sites to enter landfills (Nagapan *et al*., 2012). Nonphysical waste is related to cost

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العوامل الرئيسية المسببة للهدر في المواد في المشاريع الإنشائية في المملكة العربية السعودية

محمد القحطاني

(قدم للنشر في 1444/2/16؛ وقبل للنشر في 1444/7/4هـ)

مستخلص البحث: مع التطور العمراني والحضري السريع يزيد التركيز على الهدر في المواد في المشاريع الإنشائية وتعتبر الدراسة الشاملة للأسباب المؤدية إلى الهدر في المواد الإنشائية خطوة رئيسية لإدارة الهدر وتخفيض معدل مخلفات البناء لتقليل تأثيرها السلبي. يهدف هذا البحث إلى دراسة العوامل المسببة للهدر في المواد في المشاريع الإنشائية في منطقة الحدود الشمالية في المملكة العربية السعودية. تم جمع العوامل المسببة لهدر المواد من الأدبيات المرجعية ومن دراسة استطلاعية ومن ثم تم تصنيف العوامل إلى ست مجموعات وهي مجموعة العاملين، التصميم والتوثيق، الإدارة، المشتريات، التعامل مع المواد وعوامل خارجية. ولتحديد أهمية عوامل الهدر في المواد، تم توزيع استبيان على المهنيين العاملين في مشاريع الإنشاءات لتقييم أسباب الهدر. تم تحليل بيانات الدراسة باستخدام طريقة مؤشر المتوسطات وتم تصنيف عوامل الهدر بناء على مستوى الأهمية. بالإضافة إلى ذلك، تم تحليل بيانات الدراسة وفقاً لفئات عوامل الهدر وبناء على وجهات نظر المختصين العاملين مع المقاولين والاستشاريين. أظهرت نتائج الدراسة بأن الأسباب الأعلى تقييماً هي: تلف المواد نتيجة تعثر المشاريع وتمديدها لفترات طويلة، قلة خبرة ومهارة العمالة والفنيين، سوء استخدام المواد، تغيير التصميم خلال الإنشاء، سوء التنفيذ في الموقع وعدم اتباع أصول الصناعة والأصول الهندسية. بالإضافة إلى ذلك أظهر تحليل نتائج مجموعات العوامل أن مجموعة الأسباب المتعلقة بالعاملين هي المساهم الرئيسي في زيادة الهدر في المواد الإنشائية متبوعة بمجموعة الأسباب المتعلقة بالتصميم والتوثيق. نتائج الدراسة سوف تقدم للمتخصصين في أطراف المشاريع الإنشائية فهماً أفضل لمسببات الهدر لتطبيق حلول متوائمة لتقليل الهدر وتطوير خطط فعالة لإدارة هدر المواد الإنشائية.

كلمات مفتاحية: مشاريع الإنشاء، هدر المواد، عوامل الهدر، إدارة الهدر، المملكة العربية السعودية

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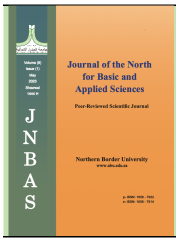

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Key causes contributing to material waste in construction projects in the Kingdom of Saudi Arabia

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Abstract: Material waste generated from construction projects is increasing significantly with rapid urbanization and construction development and has been recognized as a major environmental issue. To manage this waste and minimize its impact, a comprehensive understanding of the causes of material waste is required. The purpose of this study was to investigate the causes of such waste generation in the Northern Border Province of Saudi Arabia. Causes were identified from the literature and interviews, and then grouped into six clusters: workers, design and documentation, management, procurement, handling, and external sources. To determine the significance of material waste causes, a questionnaire survey was distributed to professionals working in construction projects. The data were analyzed using the average index method, and causes were ranked according to their importance levels. In addition, the data were analyzed according to their categories and based on the perspectives of contractors and consultants. The results showed that the top ranked five causes of material waste increase are damage to materials due to projects failure and extensions, unskilled labor and technicians, improper usage, design changes during construction, and poor implementation or failure to follow engineering and industrial principles. Analysis of cause clusters showed that worker-related causes are the major contributors to material waste generation, followed by design- and documentation-related causes. These findings will provide professionals in the construction industry with a better understanding of waste causes to apply suitable minimization solutions and develop effective waste management plans.

Keywords: Construction projects, material waste, waste causes, waste management, Saudi Arabia

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13. Hadith documentation must follow the following example: (Sahih Al-Bukhari, vol.1, p.5, hadith number 511).
14. The bibliography, list of all the sources used in the process of researching, must be added in alphabetical order using the author's last name according to the APA reference style (6th edition) in 12-font size for Arabic and 9-font size for English.

    The bibliography should be organized as follows:

    Citation from books:

    Citation from a one-authored book:

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