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Impact of Manufactured Waste Sand on the Compressive Strength of Concrete

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Abstract: Manufactured waste sand is a wildly not used material that is created by crushing larger aggregates in aggregate quarries. Due to the sustainability initiatives to save the environment, there has been a growing interest in utilizing manufactured waste sand in concrete as it can increase the concrete sustainability and lower its cost. Manufactured waste sand differs from natural sand in terms of gradations, shapes, and mineralogy where these differences can affect the fresh and hardened properties of concrete, which can raise a concern to some concrete users. In this work, concrete mixtures are prepared and made with different proportions of manufactured waste sand and the workability along with the compressive strength are measured. This work provides a correlation between the fine sand content, the compressive strength, and the workability of concrete mixtures containing manufactured waste sand. This work shows that at the fine sand content of 27%, maximum compressive strength is achieved of concrete mixtures with a blend of manufactured waste sand and natural sand.

Keywords: Manufactured waste Sand; Compressive Strength; concrete Sustainability.

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تأثير الرمال المصنعة كمنتج ثانوي على قوة ضغط الخرسانة

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(**تاريخ الاستلام:** 14-03-2025؛ **تاريخ القبول:** 19-05-2025)

الملخص: الرمال المُصنّعة هي مادة غير مستخدمة على نطاق واسع. يتم إنشاؤها عن طريق سحق الركام الأكبر حجمًا في المحاجر. ونظرًا لمبادرات الاستدامة للحفاظ على البيئة، كان هناك اهتمام متزايد باستخدام الرمال المصنعة في الخرسانة حيث يمكن أن تزيد من استدامة الخرسانة وتقلل من تكلفتها. يختلف الرمل المُصنَّع عن الرمل الطبيعي من حيث التدرجات والأشكال والتركيب الجيولوجي حيث يمكن أن تؤثر هذه الاختلافات على الخواص الطازجة والمتصلبة للخرسانة، مما قد يثير قلق بعض مستخدمي الخرسانة. في هذا العمل، يتم تحضير الخلطات الخرسانية وصنعها بنسب مختلفة من الرمل المصنع وقياس قابلية التشغيل إلى جانب قوة الضغط. يقدم هذا العمل علاقة بين محتوى الرمل الصناعي وقوة الانضغاط وقابلية تشغيل الخلطات الخرسانية. يُظهر هذا العمل أنه عند نسبة 27% من محتوى الرمل الصناعي، يتم تحقيق أقصى قوة انضغاطية للخلطات الخرسانية بمزيج من الرمل المصنع والرمل الطبيعي.

الكلمات المفتاحية: الرمل المصنع كمنج ثانوي، قوة ضغط الخرسانة، الخرسانة المستدامة.

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1. Introduction

Since concrete is considered the second most used material worldwide and has a high Co2 blueprint, there has been efforts to make the concrete as sustainable as possible. There has been an extensive consumption of natural sand in concrete so that the good quality sources of natural sand are drained out and become costly. Thus, alternative materials to the natural sand sources should be sought for not only to reduce the cost, but to save the environment as well.

The utilization of manufactured waste sand, a waste product from crushing large aggregates in the coarse aggregate production, as a replacement of natural sand either fully or partially increased duo to the sustainable and environmental initiatives [1, 2, 3]. In addition, the cost of securing a good quality natural sand source and transferring it to a construction project site could be enormous. With the availability and low cost of manufactured waste sand sources, this alternative material could mitigate the enormous demand on the natural sand sources.

Manufactured waste sands differ from natural sands in which they typically have coarser gradations, which can improve the workability of concrete by providing an aggregate size that is not found in both coarse and fine aggregates. Also, Manufactured waste sands have more angular shapes and textured surfaces as opposed to the natural sands. This can be very advantageous in increasing the concrete strength by providing more bond with cement and more interlocking and friction between aggregate particles. The availability of manufactured waste sand in an enormous piles in aggregate quarries make them a perfect alternative replacement to the natural sands, which is expensive and not available everywhere and need to be transferred from long distances.

However, utilizing manufactured waste sands in concrete can have challenges such as fines, particles that pass the No 200 (75 µm) sieve size, in the manufactured waste sand are higher, especially if not washed sufficiently. The fines amount can impact the water demand required to obtain constant workability by impacting the surface area of the aggerate particles in which higher amount of fines indicates higher surface area of the aggregates, which means higher water demand [1, 4, 5, 6]. Hence, it is important to know the amount of the fines of the manufactured waste sands prior to using them in concrete. Although the angularity and texture of manufactured waste sands are beneficial to the strength and bonding of concrete, they increase the surface area and the friction between the aggregate particles, which impact the water demand required to obtain constant workability.

The workability challenges due to the use of the manufactured waste sand are often overcome by adding more paste (binder and water) to the mixture. This increased paste content can lower the sustainability and any savings in the economy achieved by using the manufactured waste sand.

Researchers have proposed methods to use the manufactured waste sand in concrete. Some suggested using the manufactured waste sand as a replacement to the natural sand and recommend either fully or partially [1, 7, 8]. A study showed that replacing natural sand with manufactured waste sand up to 60% replacement percentage could have 20% more compressive strength and 15% more flexure strength of concrete. However, any further increasement in the manufactured waste sand replacement percentage reduced the concrete strength [9]. Nadimalla et. al. Stated that the flexural strength, the compressive strength, and the impact strength tests of concrete at 7 days, 28 days, and 90 days were greater at 100% and 50% replacement of manufactured waste sand [10]. The gain of compressive strength of manufactured waste sand concrete increased faster than that of natural sand concrete at the early age stages, but about the same at later ages [11].

Since the manufactured waste sand gradation differs from one source to another depending on many factors such as crusher type, screening process, washing method, and mineralogy of an aggregate source [6, 8], thus, proportioning manufactured waste sand in a mixture based on the replacement percentage method is not sufficient. Alturki et. al. suggested guidelines for designing concrete mixtures that need to be hand placed and finished with manufactured waste sand by modifying the Tarantula Curve proportioning method [5]

2. Tarantula Curve

The Tarantula Curve is a new approach for aggregate proportioning for concrete mixtures. This method has achieved enormous success in providing guidelines to produce workable concrete mixtures as well as pumpable concrete mixtures [12, 13]. The Tarantula Curve is highly advantageous in construction specifications and practices due to its ability to decrease the cementitious materials demand of a mixture, consequently, reduce the cost of a mixture, improve concrete durability, and lower the Co2 emissions [5, 12, 13]. Fig. 1 shows the Tarantula Curve and its boundaries.

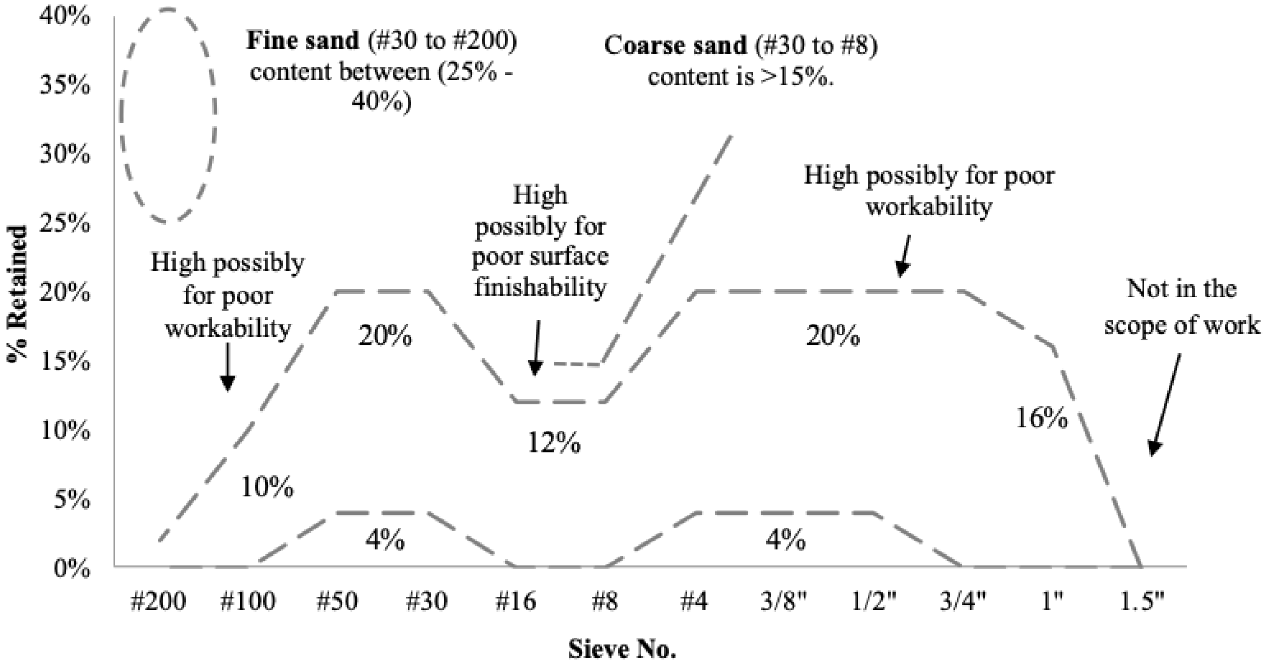

Figure 1. The boundaries of the Tarantula Curve method for combined aggregate proportioning [12].

Sokhansefat et. al. (2019) verified the Tarantula Curve boundaries by testing concrete mixtures with different aggregate gradations and workability performances and measured the aggregate packing in hardened concrete via the use of X-ray computed tomography (XCT). It was determined that the workability measurements showed segregations/ poor workability when the gradations exceeded the Tarantula Curve boundaries, by more than 20% of the coarse aggregates retained on a single sieve [14]. Alturki (2024) showed that the compressive strength reduced for the gradations that did not satisfy the Tarantula Curve boundaries of the fine aggregates retained on a single sieve [15].

The Tarantula Curve boundaries were first developed for concrete mixtures with natural fine aggregate sources only. Then, a modification was done on the Tarantula Curve to be able to proportion manufactured waste sand in a concrete mixture. Alturki et. al. modified the Tarantula Curve limits by testing concrete mixtures with various manufactured sand sources with different mineralogizes [5]. The mineralogy of manufactured waste sand affects the properties of concrete such as the workability through physical properties (gradation, shape, and texture) and water absorption. The variation in the gradations is handled by the modified Tarantula Curve boundaries. As for the shape differences, the AIMS II [16, 17]] and the uncompacted voids content test-methos A (ASTM C1252) [18] were used to study the shape of these manufactured waste sand sources and relate the effect of the shape of these sands to the workability performance of concrete mixtures containing manufactured waste sands. It was concluded that the manufactured waste sands will have shape and angularity that differ from the natural sands, which can be measured by a simple and straightforward method called the uncompacted voids content test. The higher the uncompacted voids content of manufactured waste sand, the higher the angularity and the lower the workability when used in a concrete mixture [5, 8]. Alturki et. al. found that the combined uncompacted voids content limit of 39% was able to differentiate between manufactured sand and natural sand [5]. Also, it was found that when proportioning manufactured waste sand in a mixture, the combined uncompacted voids content would determine the fine sand content limit where a minimum fine sand content of 27% was recommended when the uncompacted voids content was >39% or when using blends of manufactured waste sand and natural sand [5]. The Tarantula Curve for proportioning manufactured waste sand is shown in Fig.2.

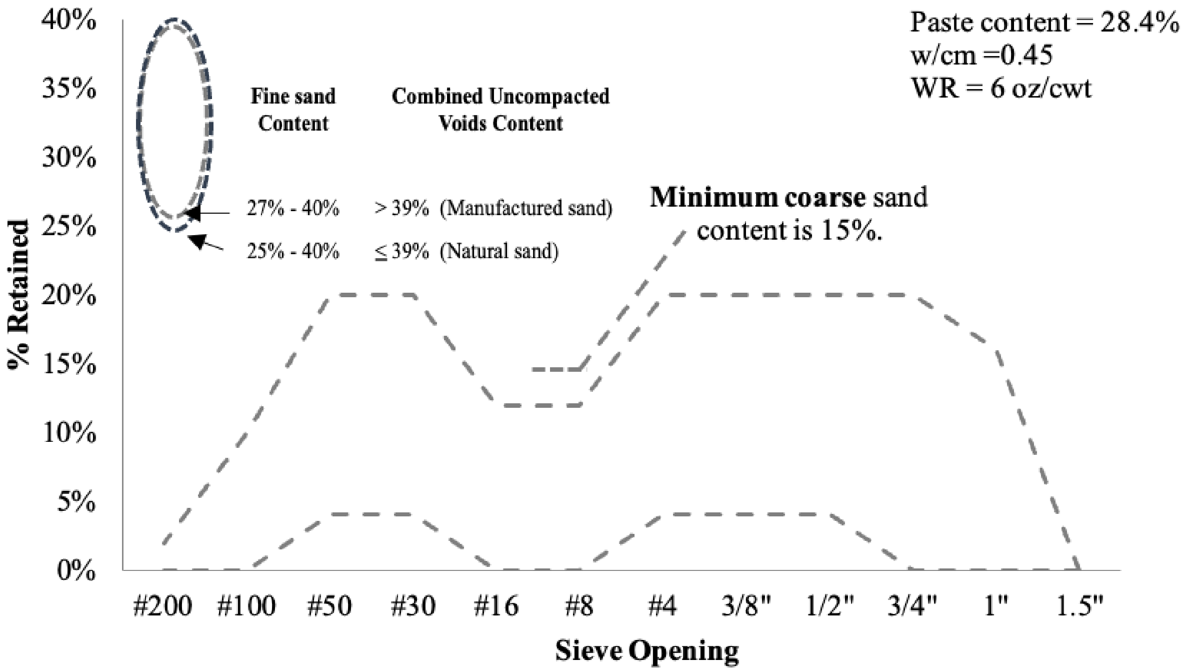

Figure 2. The Tarantula Curve limits for both the sieve sizes and the fine sand and coarse sand volumes [5]

This work aims to further validate the proposed fine sand minimum limit by Alturki et. al. by investigating the compressive strength of concrete mixtures with manufactured waste sand.

2.1 Goal of investigation

This work aims to study of the effect of manufactured waste sands on the compressive strength of concrete mixtures that need to be hand placed and finished. Also, investigating the relationship between the fine sand content limit in the modified Tarantula Curve and the compressive strength of concrete mixtures containing manufactured waste sand.

3. Materials and Methods

3.1 Materials

The concrete mixtures used in this study were prepared using Type I Portland cement that conforms to ASTM C150 [19] with a Class-C fly ash that meets ASTM C618 [20], which replaces the cement by 20% by weight. The oxide analysis for the cementitious materials is shown in Table 1. In this project, the liquid admixture was a mid-range water reducer (WR) (a lignosulfonate that meets the Type A/F classification) in accordance to ASTM C494 [21].

Table 1. Chemical Composition of the Cementitious Materials

Chemical Components	Type I (by mass %)	Fly ash (by mass %)
SiO_2	21.1	16.95
CaO	62.1	40.98
Al_2O_3	4.7	17.22
MgO	2.4	10.28
Fe_2O_3	2.6	7.4
SO_3	3.2	2.41
K_2O	0.3	0.17
Na_2O	0.2	1.13
C_2S	17.8	--
C_3S	56.7	--
C_3A	8.2	--
C_4AF	7.8	--

The coarse and intermediate aggregates were provided from a single crushed limestone source meeting the ASTM C33 [22]. The coarse aggregate had a nominal maximum aggregate size of 1 in. (25 mm) whereas the intermediate gradation had a 3/8 in. (9.5 mm) nominal maximum aggregate size.

For the fine aggregate, two natural sand sources and six manufactured waste sand sources were used in this project. The manufactured waste sands were washed, which means that the fines contents in these sands were < 7% conforming the specifications in the ASTM C33.

Fig. 3 shows the gradations of the aggregate in the individual percent retained chart as per ASTM C 136 [23] while Table 2 displays the fine aggregates properties utilized in the project.

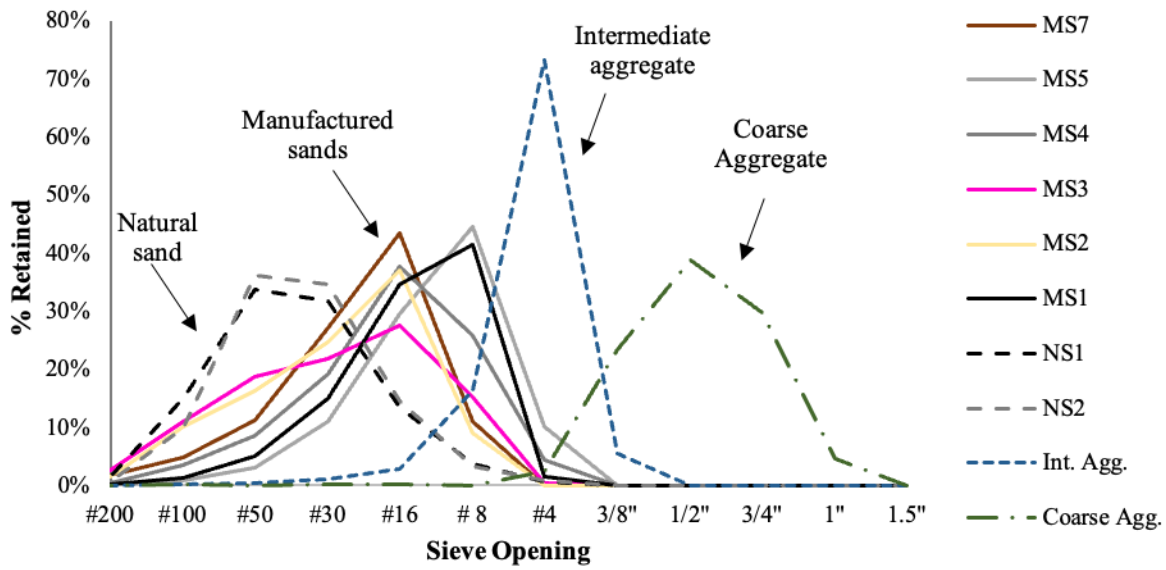

Figure 3. The gradations of aggregates obtained from the sieve analysis

Table 2. The properties of fine aggregate used in the study

Sand Type	Fine Aggregate	Fineness modulus	Specific gravity	No. 200 (%)	Fines (%)	Geology		
						Formation	Period	Rock Type
Natural sand (NS)	NS1	2.68	2.61	3.25	0.80	Terrace Deposits	--	Silica, Quartz
Manufactured Sand (MS)	NS2	2.78	2.63	0.2	0.70	Terrace Deposits	--	Silica, Quartz
	MS1	4.13	2.67	0.20	0.70	Cool Creek and McKenzie	Ordovician	Limestone- clast conglomerates
	MS2	3.06	2.65	1.19	2.10	Chico Ridge	Pennsylvanian	Limestone-Biosparite
	MS3	3.12	2.66	3.17	3.85	Chico Ridge	Pennsylvanian	Limestone-Biosparite
	MS4	4.26	2.63	1.27	2.59	Grindstone Creek	Pennsylvanian	Limestone-Biosparite
	MS5	4.43	2.75	0.20	0.70	West spring creek and Kindblade	Ordovician	Limestone-fossiliferous Igneous limestone
	MS7	3.36	2.76	1.70	1.63	Honey Creek	Ordovician	Dolomitic siltstone, Reagan Sandstone, and glauconitic sandstone

3.2 Mixture design

The gradations of the combined aggregates of concrete mixtures containing manufactured waste sand were investigated via the Tarantula Curve. This was done to determine the impact of the manufactured waste sand on the concrete compressive strength. A standard control mixture, made with the natural sand only, was used as a reference for the data in this project, presented in Table 3.

Table 3. Mixture Design for the reference Mixture

Material	Mass (lbs/yd3)	Mass (kg/m3)
Coarse Aggregate	1347	799
Intermediate Aggregate	647	348
Natural Sand	1157*	686*
Manufactured Sand	varied	varied
Cement	489	290
Fly ash	122	73
Water	275	163
WR	6 oz./cwt	3.5 ml/kg

*** These are the values with no manufactured waste sand added.**

Then, six manufactured waste sand sources were utilized in this project to replace the natural sand incrementally by volume. In Fig. 4, it is visible that as the volume of the manufactured waste sand increased, the combined gradation of the fine aggregate part changed. This is attributed to the coarseness of the manufactured waste sand gradations. The replacement of natural sand with manufactured waste sand is done in an incremental manner to achieve variable fine sand volumes (above, at, and below the fine sand limit for the modified Tarantula Curve). This was done to investigate the variability in the impacts of using the manufactured waste sand on the concrete compressive strength performance from one source to another. More details about the design of each mixture are provided in the appendix.

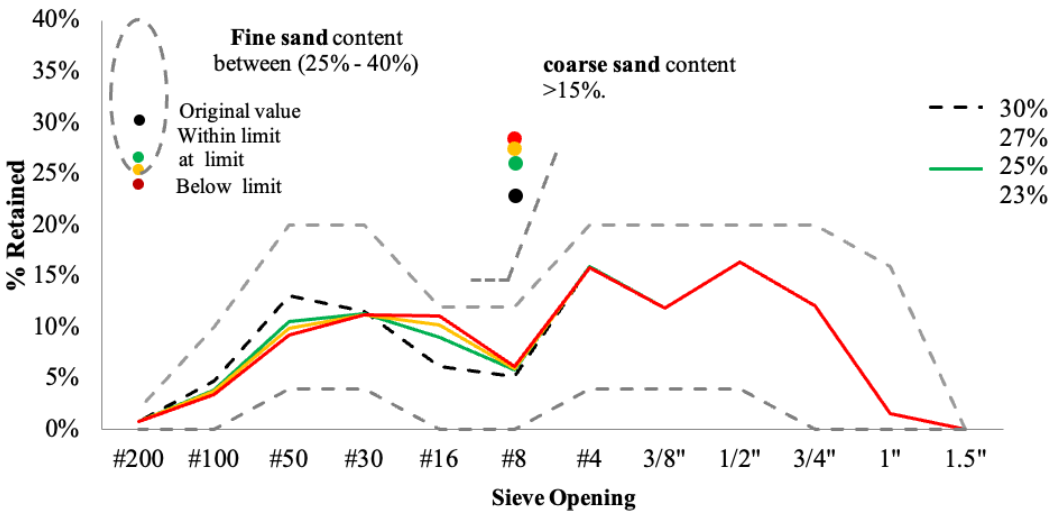

Figure 4. The Changes in the combined fine aggregate gradations because of the increase in manufactured sand volume. 2.3 Mixing procedure

The aggregates were collected from the stockpiles and brought into a temperature-controlled

(73 0F (25 0C)) laboratory room for a minimum period of 24 hours before mixing. Then, a mixing drum was used to mix the aggregates to take representative samples for moisture correction. For making the concrete mixtures, all coarse, intermediate, and fine aggregates were loaded into the mixer along with a 2/3 of the water content and mixed for three minutes to achieve the saturated surface dry condition (SSD), plus, making the mixed materials to be homogeneous. Following, the cementitious materials were added along with the remaining water and mixed for another three minutes. Next, the mixer stopped for two minutes to allow the mixture to rest while the sides of the mixer were scraped. Subsequently, the admixtures were added, and the concrete was mixed for three more minutes. The produced concrete mixture was tested using the workability performance scale and samples were prepared for the compressive strength testing.

3.3 Concrete testing

The investigated concrete mixtures were evaluated for the workability and the compressive strength performances.

3.3.1 Workability testing

A unique workability assessment method was utilized in this project. This method was developed by Cook et. all. [12] to measure an overall workability performance by evaluating the data from multiple tests. The data from each test is combined into an overall workability performance ranking. The workability performance scale and the conditions for each test are illustrated in Table 4.

Table 4. Performance Scale for Concrete Workability [12]

Workability Performance Scale	Slump (mm)	Visual observation	ICAR Rheometer			Float test	
			Static yield stress (pa)	Dynamic yield stress (pa)	Plastic viscosity (pa/sec)	Hole removal (passes)	Texture removal (passes)
Excellent (1)	203 to 152	1	<1000	<250	<10	1 to 2	1 to 2
Good (2)	152 to 102	1 to 2	1000-1500	250-500	10 to 15	3 to 4	3 to 4
Moderate (3)	102 to 51	2 to 3	1500-2000	500-1000	15 to 20	5 to 6	5 to 6
Poor (4)	51 to 0	3 to 4	>2000	>1000	>25	7 to 8	7 to 8
Unusable (5)	0	4 to 5	Too stiff	Too Stiff	Too Stiff	+9	+9

The overall workability performance for a concrete mixture can be measured by making a comparison between the results of each of the four workability tests as shown in Table 4. Each performance scale on Table 4 has a numerical range wherein an overall average number can be calculated for a concrete mixture that can be converted back into a scale as the following: excellent (0-1), good (1-2), moderate (2-3), poor (3-4), and unusable (4-5). To illustrate, Table 5 shows an example for determining an overall workability performance for a concrete mixture.

Table 5. A conversion of the workability tests results to an overall workability performance rank

Workability Test	Results example	Performance scale	Avg. numerical value for performance	Overall workability performance
Slump	127 mm	Good (2)		
Visual observation	1	Excellent (1)		
Static Yield Stress	1502 Pa	Moderate (3)		
Dynamic Yield Stress	458 Pa	Good (2)		
Plastic Viscosity	18 Pa	Moderate (3)	**2.4**	**Moderate**
Float Test (holes)	5	Moderate (3)		
Float Test (Texture)	6	Moderate (3)		

3.3.2 Compressive strength testing

Standard cylinder molds were used to prepare specimens for the compressive strength test with a size of 4 in. x 8 in. (100 mm x 200 mm). Molds were filled and consolidated as per ASTM C31 [24]. The samples were stored in a temperature-controlled and moisture-controlled room for curing purposes, as specified in the ASTM C31. Concrete compressive strength test was conducted at 7-day and 28-day on hardened concrete in accordance with ASTM C39 [25].

4. Results and discussion

4.1 Concrete mixtures with manufactured waste sand

The purpose of this study was to explore the effects of the variable manufactured waste sand gradations and sources on the compressive strength of concrete. This was done by using six manufactured waste sand sources when they incrementally replaced the natural sand by volume of fine aggregates in which the fine sand contents (sum of the No. 30 (600µm) to No. 200 (75 µm)) vary (above, at, and below the limit). The detailed results can be found in the appendix.

Fig. 5 and Fig. 6 plot the mixtures for 7- day and 28 – day compressive strength compared to the fine sand content. The color of each data point changes depending on the performance of the workability. Further, the manufactured waste sand replacement range by volume is numerically shown for each series of data points for fixed fine sand volume.

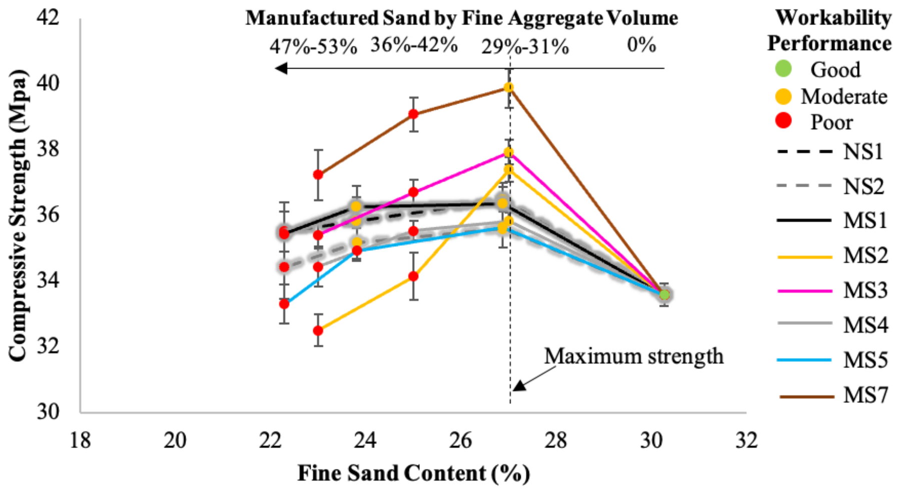

Figure 5. The 7-day compressive strength of the concrete mixtures versus different volumes of fine sand.

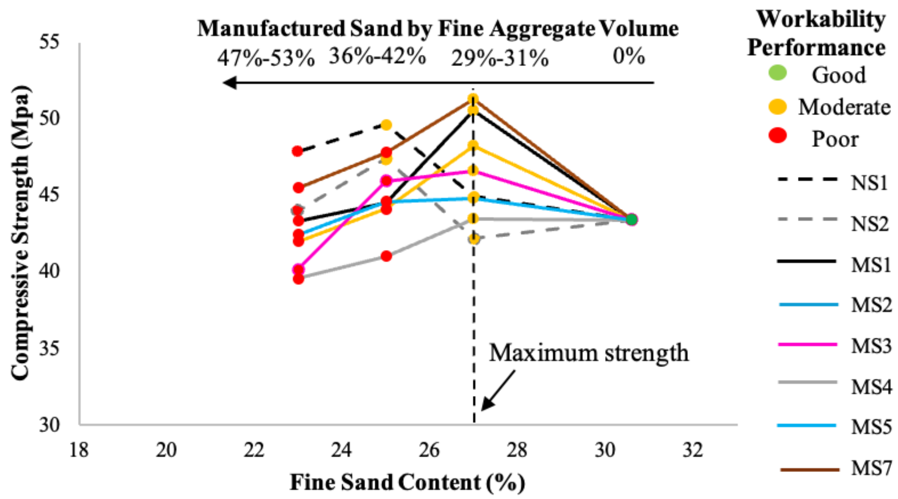

Figure 6. The 28-day compressive strength of the concrete mixtures versus different volumes of fine sand

It can be noted from Fig. 5 and Fig. 6 that the mixtures had a reduction in the fine sand content as the volume of the manufactured waste sand increased. This could be attributed to the coarser gradations of manufactured waste sand in comparison to the natural sand. It should be noticed that as the fine sand content decreased or as the manufactured waste sand content increased, the compressive strength of the concrete mixtures increased while the workability performance decreased.

For the 7-day compressive strength, it was observed from Fig. 5 that the compressive strength of concrete mixtures containing manufactured waste sand increased as the volume of manufactured waste sand increased. This work shows that the manufactured waste sand can replace the natural sand in the range between 29% and 31% and still gain compressive strength. However, higher replacement percentages led to a decline in the compressive strength and the workability performance becomes poor.

Note that at a fine sand content of 25% in the mixtures, the performances of compressive strength for all the manufactured waste sand mixtures decreased with poor workability performance. The amount of manufactured waste sand replacement varied from 36% to 42% at this fine sand content. It is essential to observe that even though the replacement levels and the gradations of manufactured waste sands were variable, the compressive strength of the mixtures declined. This strengthens the importance of the fine sand content in the mixture. This also reinforces that it is not acceptable method to estimate the manufactured waste sand mixture performance using replacement percentages. Conversely, the modified Tarantula Curve boundaries should be utilized with the combined gradation and put a special focus on the fine sand content in the aggregate combined gradation.

For the 28-day compressive strength presented in Fig. 6, there seems to be a drop-in the compressive strength if there is poor workability in the mixture, but this drop does not appear to be as significant. This difference in behavior could be attributed to the weakness of the paste at 7-days. Thus, the strength of the concrete is dominated by the aggregate. However, in later ages, the concrete strength is a combination of the strength of the paste and the aggregate. This work agreed with other studies findings where the presence of manufactured waste sand in a concrete mixture can improve the concrete compressive strength [3, 5, 21].

4.2 The minimum fine content to proportion manufactured waste sand

While the manufactured waste sand volume in a concrete mixture is determined by the fine sand content [5], a minimum fine sand content could be established to be able to proportion manufactured waste sand in concrete and achieve maximum compressive strength. To do that, it can be seen from Fig. 5 and Fig. 6 that the maximum compressive strength of mixtures containing manufactured waste sand occurred at a fine sand content of 27%. This confirms the minimum fine sand content to proportion manufactured waste sand in concrete and still achieve acceptable workability. Once the workability of the mixtures changed to poor, the compressive strength decreased.

It is important to know that these recommendations apply for the materials and mixtures investigated in this work; still, it would be beneficial to have more sources to enlarge this work.

5. Practical significant

Manufactured waste sands have started to be used more often in the concrete industry. Even though their usage in concrete mixtures can increase the compressive strength, the workability can be reduced at higher amounts, which will weaken the concrete eventually. This research provides further validations to the fine sand content limits to proportion manufactured waste sands in concrete mixtures by investigating the compressive strength performance of concrete mixtures containing manufactured waste sands. Also, correlate the compressive strength performance to the workability performance of concrete mixtures containing manufactured waste sands.

This work shows that successful flatwork can be produced by following the modified guidelines for the Tarantula Curve by replacing 30% of the natural sand with manufactured waste sand and achieve the maximum compressive strength with satisfactory workability. Yet, this percentage changes based on the source, and the fine sand content is the preferrable method to determine the replacement level in the mixture. Even though using manufactured waste sands in concrete impacted the compressive strength positively, their impact on the durability could be researched in the future studies.

6. Conclusion

This work quantified how the use of manufactured waste sands in concrete impacts the compressive strength of concrete and relate the compressive strength performance to the workability performance using the modified Tarantula Curve concrete design method. It is important to acknowledge that the manufactured waste sands utilized in this study were washed, which means that the fines amounts were less than the ASTM C 33 limit of 7%. In this project, the fines fluctuated between 3.17% and 0.70%.

The following are the specific findings from this work: The fine sand content, sum of No. 30 to No. 200 (600µm to to 75 µm) is essential in determining the manufactured waste sand amount that can be used in concrete based on the compressive strength. This work validates that the minimum fine sand content of 27% is recommended when blending manufactured waste sand with natural sand. Whenever the workability performance is poor due to exceeding the minimum fine sand content of 27%, the compressive strength decreased.

This work guides how to produce strong and workable concrete mixtures that contain manufactured waste sand, which is a vital approach to enhance the usage of manufactured waste sand in concrete mixtures for satisfactory flatwork.

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8. Appendix A

Table A 1. Overall Workability Performance Results of the Concrete Mixtures

Fine sand	Blended manufactured sand	Combined N0.200	Combined Fines	Overall workability performance	Static Yield Stress (Pa)	Dynamic Yield Stress (Pa)	Plastic Viscosity (Pa/sec)	Slump (mm)	Float Test		Visual Observation	Compressive strength (MPa)	
									Hole	Texture		7-day	28-day
30.6%	Original NS	3.25%	0.80%	Good	1304	384	25	152	4	3	1.0	33.59	43.41
27%	NS1 (14%)	1.04%	0.78%	Moderate	--	--	--	165	6	5	1.4	36.48	44.93
	NS2 (15%)	0.98%	0.78%	Moderate	1436	485	20	178	5	5	1.4	35.60	42.18
	MS1 (29%)	2.18%	0.97%	Moderate	2169	564	19	152	7	6	2.0	36.35	50.55
	MS2 (29%)	3.23%	1.04%	Moderate	1970	649	20	146	8	6	2.0	37.93	46.62
	MS3 (30%)	2.21	1.02%	Moderate	1800	435	20	127	8	7	2.0	35.83	43.44
	MS4 (28%)	3.21	0.88%	Moderate	1370	428	18	140	8	7	2.0	34.94	44.77
	MS5 (30%)	2.53%	0.95%	Moderate	1791	369	28	159	8	7	2.0	35.63	42.42
	MS7 (30%)	2.53%	0.95%	Moderate	1791	369	28	159	8	7	2.0	39.87	51.30
25%	NS1 (27%)	0.63%	0.77%	Moderate	--	--	--	140	7	5	1.4	35.81	49.61
	NS2 (27%)	0.63%	0.77%	Moderate	1816	499	20	127	6	6	2.0	35.17	47.40
	MS1 (40%)	1.91%	1.07%	Poor	2262	769	25	146	8	7	2.6	36.26	44.54
	MS2 (41%)	3.22%	1.19%	Poor	2714	816	23	140	8	9	2.6	36.70	45.92
	MS3 (43%)	1.94%	1.14%	Poor	1938	807	27	121	11	9	2.2	35.54	41.02
	MS4 (36%)	3.20%	0.91%	Poor	1507	457	27	127	10	12	2.2	35.63	42.42
	MS5 (42%)	2.33%	1.03%	Poor	2500	683	27	108	12	10	2.4	34.94	44.77
	MS7 (42%)	2.33%	1.03%	Poor	2500	683	27	108	12	10	2.4	39.07	47.79
23%	NS1 (35%)	0.51%	0.76%	Poor	--	--	--	121	12	12	3.0	35.51	47.88
	NS2 (35%)	0.51%	0.76%	Poor	2638	531	26	102	8	10	3.2	34.43	43.95
	MS1 (50%)	1.74%	1.16%	Unusable	2295	746	32	133	10	9	3.5	35.45	43.35
	MS2 (51%)	3.21%	1.35%	Unusable	3211	920	30	127	9	10	2.8	35.42	40.18
	MS3 (53%)	1.78%	1.26%	Unusable	3923	754	48	76	15	10	3.8	34.45	39.58
	MS4 (44%)	3.19%	0.94%	Unusable	4100	750	43	108	13	11	3.5	33.31	44.69
	MS5 (51%)	2.2%	1.09%	Unusable	4522	840	45	108	15	11	3.5	37.23	45.48
	MS7 (51%)	2.2%	1.09%	Unusable	4522	840	45	108	15	11	3.5	37.23	45.48