Effects of Water-Reducing Admixture on the Compressive Strength of Concrete Using Crushed Mangima Stone as Fine Aggregate

Jonathan B. Calibara* and Ruel R. Cabahug
College of Engineering and Architecture
University of Science and Technology of Southern Philippines – Cagayan de Oro
Cagayan de Oro City, 9000 Philippines
*jonathancalibara@gmail.com

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Abstract

Crushed Mangima stone as an alternative concrete aggregate has been studied and found to provide concrete with comparable compressive strength to that of the conventional concrete. This study investigated the effect of water-reducing admixtures in concrete production using crushed Mangima stone as fine aggregate. Water-reducing admixture with a variance of 0.5, 1.0, and 1.5% by weight of cement was added to the concrete mixture. A water-cement ratio of 0.57 was used for this study. Samples were cured at seven, 14, and 28 days and tested for compression after each curing period. The compressive strength of concrete using water-reducing admixtures showed an early strength and passed the minimum requirement of 3,000 psi. Results revealed that through the use of admixtures, compressive strength obtained from all samples was higher than the control mixture. This means that using crushed Mangima stone has its potential to be used as fine aggregate in a structural concrete mixture with the addition of water-reducing admixture.

***Keywords**:* Mangima stone, concrete cylinder, compressive strength, fine aggregate, water-reducing admixture

1. Introduction

Concrete is a composite material that consists of aggregates (fine and coarse) and binding medium made of cement and water. Concrete is one of the most versatile construction materials in the world with an estimated production of 25 billion metric tonnes each year (World Business Council for Sustainable Development [WBCSD], 2009).

With the use of natural aggregates which are normally sourced from rivers, a serious problem on its availability has become an environmental concern

(Sérifou *et al*., 2013). Several alternative materials have been introduced to resolve such concern by utilizing non-conventional aggregates (Cabahug *et al*., 2011; Adinkrah-Appiah, 2018). These include blast furnace slags (Levy, 2012), broken glass (Kuruppu and Chandratilake, 2012; Gautam *et al*., 2012; Maschio *et al*., 2013), fiberglass waste materials (Mohamed *et al*., 2016), plastics (Jibrael and Peter, 2016; Mahesh *et al*., 2016; Jaivignesh and Sofi, 2017; Thorneycroft *et al*., 2018), sintered pellets (Nair and Ramamurthy, 2010), recycled concrete (WBCSD, 2009; Sérifou *et al*., 2013) and other relevant materials.

Mangima stone (*Phyllite schist*) is a mineral commonly found in Bukidnon province, specifically at Mangima, Manolo Fortich, Bukidnon, Philippines. Mangima stone is a metamorphic rock that develops under high temperature and pressure by recrystallizing pre-existing rocks. During the process of metamorphosis, the rock shapes and remains completely solid, and pressure is often anisotropic. This leads to the preferred orientation of newly formed minerals in that process. Although the Mangima stones often differ in color, the stone has similar properties. The three types of Mangima stones are schist, phyllite, and phyllite schist. This stone is non-metallic, naturally occurring, solid, inorganic, and has an ordered arrangement of internal crystals (Tomkeieff *et al*., 1983; Schmid *et al*., 2007).

Mangima stones are used as decorative tiles for wall finishing in the building construction industry due to its rock accent effect which also improves the aesthetic appearance due to natural rock colors. When cut into tiles, these Mangima stones entail considerable waste, which is mostly overlooked as waste materials as shown in Figure 1. With the abundance of these natural rocks in the region, alternative uses, bringing sustainable economic benefits to these natural resources, need to be identified.

One of the alternative uses of Mangima stones is to crush them into sizes applicable to concrete production. A previous study of Cabahug *et al*. (2011) showed the potential of the coarse Mangima aggregates for concrete. Test results showed that partially replacing conventional aggregates (natural gravel) provided passing compressive strength required for structural concrete – above 3,000 psi.

Figure 1. Wasted cuts of Mangima stone

The use of chemical admixtures in concrete has evolved in the intent of producing a better performance of concrete. Spiratos and Jolicoeur (2000) had anticipated the future uses of admixture in concrete technology such that development and progress in the building industries had highly increased. The improvement of concrete using admixtures has been thoroughly studied by several researchers which provided better concrete strengths by providing higher compressive strength concrete (Meyer and Perenchio, 1979; Yamato *et al*., 1998; Erdoğdu, 2005; Katz and Baum, 2006; Pereira *et al*., 2012a, 2012b; Nagrockiene *et al*., 2013).

Owing to the positive result obtained by Cabahug *et al*. (2011), this study investigated the potential of Mangima stone as fine aggregates with the addition of water-reducing admixtures for the production of structural concrete. Water-reducing admixtures with a variance of 0.5, 1.0, and 1.5% admixture by weight of cement was added to the concrete mix and then cured for seven, 14, and 28 days.

2. Methodology

2.1 Materials

2.1.1 Mangima Stone

The raw material (Mangima stone) was mined at Mangima, Manolo Fortich, Bukidnon. The local government allows the quarrying of the material. The authors had gathered the wasted cuts from the stone. The wasted cuttings were grounded into fine material (sand) for use in the concrete mixture. The authors used a hammer to smash the stone into smaller parts.

Figure 2. The Mangima stone

The initial screening of the crushed Mangima stone was done through sieving. It needed to pass through sieve number 4 (4.75 mm) and retain in sieve number 200 (0.075 mm). The quality tests on the crushed stone as fine aggregate were performed according to American Society for Testing and Materials (ASTM) standards. In designing the concrete mix, the minimum test requirement was sieve analysis, fineness modulus, unit weight, specific gravity and water absorption. The crushed Mangima stone was washed and cleaned before it was used in a concrete mix.

2.1.2 Sika Admixture

The Sika admixture was given by the satellite branch of SIKA Philippines at Kauswagan, Cagayan de Oro City. A professional representative from Sika had proposed the chemical admixtures. The said admixtures were used in some Philippine ventures. The SIKA admixture used was SikaPlast-2000 P4 GN – a superplasticizer for concrete in the 3rd generation, low-mid range. The percentages of admixtures used in the mixtures were 0.5, 1.0 and 1.5%. In the concrete mix, certain proportions were used as an additive.

2.1.3 Conventional Sand and Coarse Aggregates

Supplied by a reliable supplier, the sand and coarse aggregates used were quarried from the Tagoloan River. The sample's accuracy was checked before utilization according to the ASTM standard. It was washed and cleaned before it was further used as aggregates.

2.1.4 Cement

Commonly used for general construction, Type-1 Portland cement was utilized in the concrete mixture. Its loss of ignition (Loi) and specific gravity were tested per ASTM standards as part of the requirements in concrete design.

2.2 Physical Tests for Aggregates

With the minimum requirement in a concrete mix design, the physical tests for aggregates included sieve analysis per ASTM C136/C136-19 (2019), specific gravity for coarse and fine by ASTM C127-15 (2015) and ASTM C128-15 (2015) and unit weight in accordance to ASTM C29/C29-17a (2017).

2.3 Proportioning the Mixture for the Design Mix

The concrete mixing method used was based on the absolute volume approach as illustrated by American Concrete Institute (ACI) 211.1-91 (ACI, 1991). The analysis used amounts of admixture as an additive used in the concrete mixture. Tables 1 and 2 show the various construction mix as fine aggregate for ordinary concrete mixing using sand and crushed Mangima stone. In the said tables, the optimal combination such as water-cement ratio, cement weight, water, sand, and crushed Mangima stone are shown.

Tables 1 and 2 shows the amount of cement, fine aggregate (conventional sand or crushed Mangima stone), coarse aggregate, and water. The desired weight of cement was 22.1 kg, fine aggregate (conventional sand or crushed Mangima stone) was 44.2 kg, coarse aggregate of 70.2 kg, and 12.5 L of water. Control mix, design Mix-A, Mix-B, and Mix-C, had 0, 0.5, 1.0 and 1.5% of admixtures, respectively.

Table 1. Design mix used for ordinary concrete mix using sand as conventional fine aggregate

Type of Mix	Desired Mixes (% Admixture)	Curing Period	No. of Samples	w/c ratio	Water (L)	Cement (kg)	Sand (kg)	Coarse Aggregate (kg)
Ordinary concrete mix using conventional sand as fine aggregate	Control Mix (0% Admixture) SCM	7 14 28	3 3 3	0.57	12.5	22.1	44.2	70.2
	Mix-A (0.5% Admixture) SDM-A	7 14 28	3 3 3	0.57	12.5	22.1	44.2	70.2
	Mix-B (1.0% Admixture) SDM-B	7 14 28	3 3 3	0.57	12.5	22.1	44.2	70.2
	Mix-C (1.5% Admixture) SDM-C	7 14 28	3 3 3	0.57	12.5	22.1	44.2	70.2

Table 2. Design mix used for concrete mix using crushed Mangima stone as fine aggregate

Type of Mix	Desired Mixes (% Admixture)	Curing Period	No. of Samples	w/c ratio	Water (L)	Cement (kg)	Crushed Mangima (fine aggregate) (kg)	Coarse Aggregate (kg)
Ordinary concrete mix using crushed Mangima stone as fine aggregate	Control Mix (0% Admixture) MCM	7 14 28	3 3 3	0.57	12.5	22.1	44.2	70.2
	Mix-A (0.5% Admixture) MDM-A	7 14 28	3 3 3	0.57	12.5	22.1	44.2	70.2
	Mix-B (1.0% Admixture) MDM-B	7 14 28	3 3 3	0.57	12.5	22.1	44.2	70.2
	Mix-C (1.5% Admixture) MDM-C	7 14 28	3 3 3	0.57	12.5	22.1	44.2	70.2

Table 3 shows the volume of admixture used for the ordinary concrete mix using conventional sand and crushed Mangima stone as fine aggregate. Adding of admixture to the mixture using Conventional sand and crushed Mangima stone was observed and analyzed to determine its effect on the compressive strength of concrete.

Table 3. Volume of admixture used for the ordinary concrete mix using conventional sand and crushed Mangima stone as fine aggregate

Mix with admixture	Conventional Sand (Admixture Content) (L)	Crushed Mangima Stone (Admixture Content) (L)
Mix-A (0.5% admixture)	0.1105	0.1105
Mix-B (1.0% admixture)	0.221	0.221
Mix-C (1.5% admixture)	0.3315	0.3315

2.4 Slump Test

According to ASTM C143/C143M-15a (2015), slump tests must be checked to ensure the integrity of the concrete mix. During concrete mix slump test, observance of the water-cement ratio was checked and recorded. To assess the impact of water-admixture on the concrete mix, the authors used 0.57 waste-cement ratio.

2.5 Procedure in Making and Curing Concrete Cylinder

If the concrete mixture is finished and the slump test is completed properly, a concrete cylinder sampling will be performed as per ASTM C31/C31M-19a (2019). Using a steel plate, the excess mixture was scraped from the mold's open side. The complete sample count consisted of 72 cylinders of concrete. One sample collection was equivalent to three sample numbers (seven, 14, and 28 days).

The concrete used to make the molded specimens shall be tested according to ASTM C31/C31M-19a (2019) after all on-site changes have been made to the proportions of the mixture, including the addition of mixing water and admixtures. Initial healing and cure specimens with free water held at surface temperature (23 ± 2 °C) within 30 min after removal of the molds using water storage tanks or moist rooms.

2.6 Determination of Compression Strength

The compression test was conducted in compliance with ASTM specification, ASTM C39/C39-18 (2018). The test was carried out in and results was given by an independent research laboratory accredited by Department of Public Works and Highways (DPWH).

2.7 Statistical Analysis

To determine the significant difference of the data in the experiment from P-value and F-value of admixture and curing period, and the interaction between admixtures and curing period, the two-way analysis of variance (ANOVA) was performed since the analysis involved two different samples. The two different samples were the compressive strength of concrete using conventional sand and compressive strength using crushed Mangima stone as fine aggregate. Two factors were considered as part of the analysis – the admixtures added and curing period, and the interactions between the admixtures and curing period.

3. Results and Discussion

3.1 Compressive Strength

3.1.1 Ordinary Concrete Mix using Sand as Fine Aggregate

The compressive strength of ordinary concrete mix using conventional sand as fine aggregate was one of the parameters to determine the mechanical properties of concrete. Table 4 shows the average compressive strength test results of ordinary concrete mix using conventional sand as fine aggregate. The control mix was lower compared with design mix-A with 0.5% admixture. In this particular mix, the compression results showed an early strength and it passed the minimum requirement of 3000 psi.

Table 4. Test results on the average compressive strength of ordinary concrete mix using conventional sand as fine aggregate

	Control Mix (0% Admixture) SCM		Mix-A (0.5%Admixture) SDM-A		Mix-B (1.0% Admixture) SDM-B		Mix-C (1.5% Admixture) SDM-C	
	Curing Period	Strength (psi)	Curing Period	Strength (psi)	Curing Period	Strength (psi)	Curing Period	Strength, psi
Ordinary concrete mix using conventional sand as fine aggregate	7	3273	7	3793	7	3660	7	3777
	14	3603	14	4410	14	4530	14	3897
	28	4123	28	4690	28	4557	28	4083

Figure 3 demonstrates a remarkable and reasonable result in the mean compressive strength of an ordinary concrete mix using sand as a fine aggregate. The concrete compressive strength was higher than the control mix (SCM) with 0.5% (Mix-A) and 1.0% (SDM-B) additional admixture. Adding admixture by 1.5% (Mix-C), however, shows a slight drop-off on the graph. Depending on the minimum requirement of 3000 psi including the control mix, the tests of seven, 14, and 28 days were over 3000 psi. The design Mix-A (SDM-A) displayed the maximum compressive resistance of 4690 psi in 28 days. The results of all 28-day compression testing using admixture improved the strength slightly.

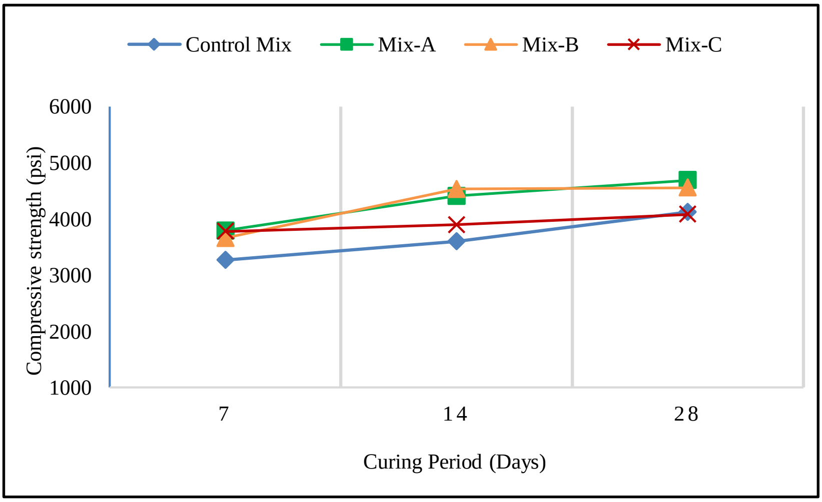

Figure 3. Average compression strength of ordinary concrete using conventional sand as fine aggregate

3.1.2 Concrete Mix using Crushed Mangima Stone as Fine Aggregate

The water-cement ratio was a challenge since crushed Mangima stone absorbed more water. The 0.57 w/c ratio was just enough to use as a control mix value, which is lesser. Figure 4 reveals an excellent outcome that passed the minimum requirement (3000 psi). For 1.0% (Mix-B) and 1.5% (Mix-C) admixture, the concrete compressive power was greater than the control mix. However, adding 0.5% admixture (Mix-A) indicates a small drop-off on the graph.

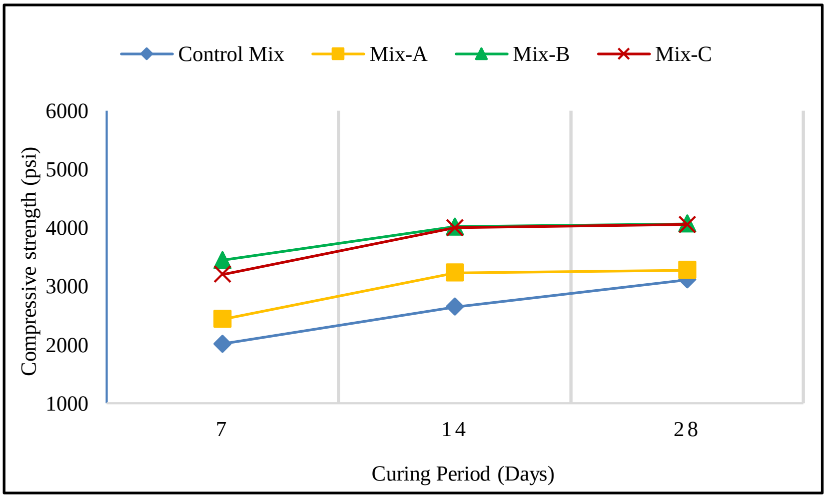

Figure 4. Average compression strength of concrete using crushed Mangima stone as fine aggregate

According to the specifications of ASTM C494/C494M-05a (2005), the compressive and flexural strength of the concrete comprising the admixture measured at any test age shall not be less than 90% achieved at any test age. The goal of this restriction is to ensure that the compressive or flexural strength of the concrete that contains the admixture being measured does not decrease with age.

Table 5 shows the test results on the average compressive strength of concrete mix using crushed Mangima stone as fine aggregate. As per the result, the control mix was lower compared with the design Mix-B with 1.0% admixture.

Table 5. Test results on the average compressive strength of concrete mix using crushed Mangima stone as fine aggregate

	Control Mix (0% Admixture) MCM		Mix-A (0.5% Admixture) MDM-A		Mix-B (1.0% Admixture) MDM-B		Mix-C (1.5% Admixture) MDM-C	
	Curing Period	Strength (psi)	Curing Period	Strength (psi)	Curing Period	Strength (psi)	Curing Period	Strength (psi)
Ordinary concrete mix using Mangima stone as fine aggregate	7	3273	7	2440	7	3447	7	3207
	14	3603	14	3233	14	4020	14	4000
	28	3113	28	3280	28	4070	28	4057

The compression results of design Mix-B is slightly higher than that of the design Mix-C in seven, 14, and 28 days. Crushed Mangima stone without admixture was weaker compared with the designs having added admixture. All 28 days test results passed the 3000 psi minimum requirement for structural concrete.

3.2 ANOVA and T-test

Tables 6 and 7 display the various values that can be used to determine how important they are to others. The following samples were considered: ordinary concrete mix using conventional sand and crushed Mangima stone fine aggregate concrete mix. The effects of compressive strength were analyzed in to determine the significance between admixture and curing period, and the relationship between admixtures and curing period.

3.2.1 ANOVA Compressive Strength for Ordinary Concrete Mix

The analysis considered the confidence level of 95%, therefore the value $p < 0.05$ is significant. It is less than 0.05 for admixtures having 0.000 of P-value. The null hypothesis is rejected (admixture would not affect the compressive intensity of the concrete mix). Curing period having as P-value 0.000 is also less than 0.05. The null hypothesis (curing would not affect the concrete mix's compressive strength) is dismissed. The relation between admixture and curing period had a value of 0.233 – greater than 0.05.

Table 6. ANOVA (conventional sand)

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	13	6682269	514021	6.50	0.000
Cylinders	2	237439	118719	1.50	0.245
Linear	5	5745436	1149087	14.54	0.000
Admixture	3	2375431	791810	10.02	0.000
Curing Period	2	3370006	1685003	21.32	0.000
2-Way Interactions					
Admixtures-curing period	6	699394	116566	1.47	0.233
Error	22	1738894	79041		
Total	35	8421164			

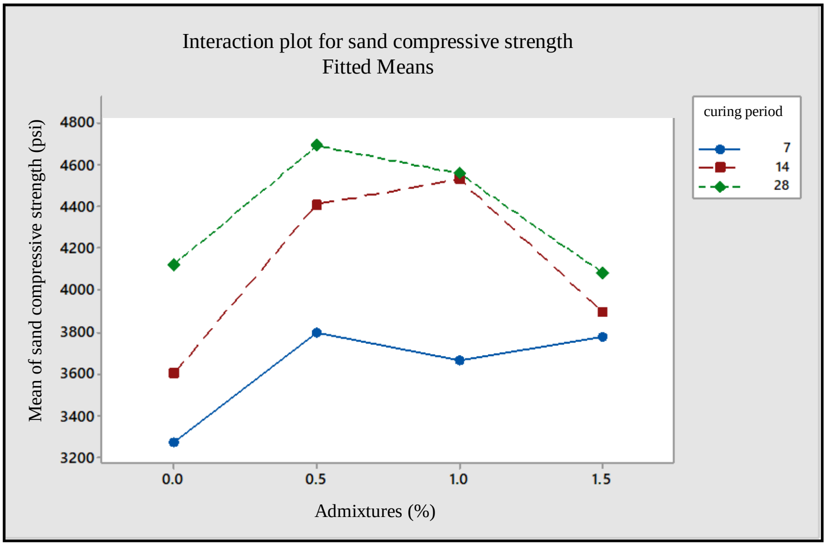

Figure 5. Mean of sand compressive strength on admixtures and curing period

3.2.2 ANOVA Compressive Strength Using Crushed Mangima Stone

With the same trust level of 95%, admixtures and curing P-value is 0.000, lower than $p < 0.05$. Thus, null hypothesis (admixtures and curing would have no impact on the concrete compressive strength) is denied. The P-value of the admixture and cure relationship is 0.501 – greater than 0.05. Hence, the null hypothesis (the relationship between admixtures and curing period) is not rejected. The impact did not have any effect on the concrete's compressive strength.

Table 7. ANOVA (Mangima stone)

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	13	16243828	1249525	12.65	0.000
Cylinders	2	139	69	0.00	0.999
Linear	5	15699994	3139999	31.78	0.000
Admixture	3	10979622	3659874	37.05	0.000
Curing Period	2	4720372	2360186	23.89	0.000
2-Way Interactions					
Admixtures-curing period	6	543694	90616	0.92	0.501
Error	22	2173461	98794		
Total	35	18417289			

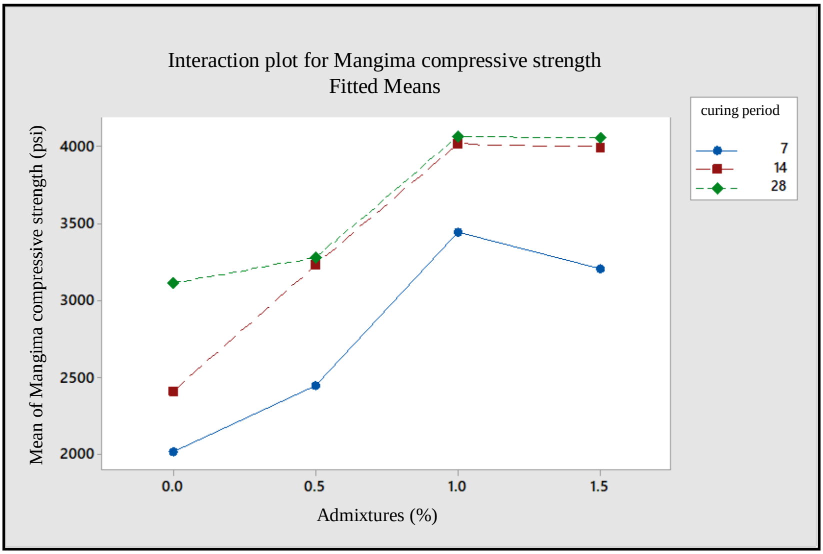

Figure 6. Mean of crushed Mangima stone compressive strength on admixtures and curing period

3.2.3 Two-Sample T-*t*est on the Compressive Strength of Concrete using Sand and Crushed Mangima Stone

The P-value was determined using Minitab software to know the difference between samples. For sand (0.0% admixture) vs. Mangima (0.0% admixture), the P-value is 0.000 – less than 0.05. Therefore, the null hypothesis (there is no difference between the samples mean) is rejected.

The P-value of the concrete using sand (0.0% admixture) and concrete using Mangima (0.5% admixture) is 0.000, the P-value is less than 0.05. Therefore, the null hypothesis (there is no difference between the samples mean) is rejected.

The P-value of the concrete using sand (0.0% admixture) and concrete using Mangima (1.0% admixture) is 0.332, the P-value is greater than 0.05; therefore, failing to reject the null hypothesis (no difference between the samples mean).

For sand (0.0% admixture) vs. Mangima (1.5% admixture), the P-value is 0.667, greater than 0.05; hence, failing to reject the null hypothesis (no difference between the samples mean).

The two-way sample used sand as the standard bases. The T-*t*est determines whether using crushed Mangima stone with admixture will have a difference between the means. In this section, 0.0 and 0.5% admixtures had their differences in the means on the compressive strength of concrete.

4. Conclusion and Recommendation

This study assessed the potential of crushed Mangima stone as a fine aggregate. The minimum requirement for structural concrete is 3000 psi. A water-reducing admixture was applied to improve the use of crushed Mangima stone as a fine aggregate to achieve the minimum strength of structural concrete. It was found out that using the 0.57 w/c ratio of crushed Mangima stone as fine aggregate in a concrete mix appeared to be acceptable for this type of material. Also, the strength of the control mix using crushed Mangima stone without admixture was lesser than 3000 psi. Likewise, the water-reducing admixture was generally superior to the reference concrete with no admixtures. With the presence of admixtures, the concrete produced early strength and passed the minimum requirement of 3000 psi. Hence, the crushed Mangima stone has the potential to be used as a fine aggregate. The 1.0% water-reducing admixture gave the highest compressive aggregate when water-reducing admixture was added to the concrete mixture.

Having found the potential use of Mangima stone stone for concrete aggregate, a mechanical crusher could help the Mangima stone to be crushed into a desired aggregate sizes. It is also recommended to use other chemical admixture that can be an option as an additive to a concrete mixture depending on its purpose. Lastly, future studies should use crushed Mangima stone in both coarse and fine aggregates and add admixture on different percentage to determine the optimum design mix for structural concrete production.

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