INFLUENCE OF MICROFINE-CONTAMINATED SAND FROM MANDULOG RIVER SYSTEM IN ILIGAN CITY, PHILIPPINES ON THE PERFORMANCE OF CONCRETE

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Abstract

The presence of microfines in the concrete matrix is a concern, as it affects the fresh and hardened properties of concrete. As such, aggregates quarried from rivers with considerable amounts of microfines need to undergo a pretreatment process to remove the microfines, which could be a costly endeavor. This is the case for aggregates quarried from Mandulog River in Iligan City, Philippines, where microfines are present. This paper, therefore, set out to find the influence of the microfines on the performance of concrete by determining its effect on the slump, the water demand, and compressive strength of concrete with microfines from 1 to 6% at 1% increment of the weight of fine aggregates. Experimental results showed that microfines in concrete could affect the slump and water demand for concrete minimally. In particular, the compressive strength at the 28th-day curing period was not significantly affected; thus, it can be concluded that microfines of up to 6% of the weight of fine aggregates can be tolerated for concretes produced using aggregates from the Mandulog River system.

Keywords: microfines; concrete; slump; water demand; compressive strength.

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1. Introduction

Microfines are those materials finer than 75 µm [1] which are generally present in fine aggregates. In manufactured sand, for example, as high as 20% microfines are present as a result of rock crushing [1, 2]. Microfines are also present in river-quarried fine aggregates, which are at times contaminated with deleterious materials such as clay and silt [3]. Typically, naturally occurring microfines are classified as stone dust, clay particles, or calcium carbonate [4]. Microfines are said to have both beneficial and detrimental effects on the performance of fresh and hardened concrete. This is primarily due to the difference in the mineralogy of microfines (e.g., those contaminated with clay) and their physical attribute, such as having a high surface area. Research has shown that the mineralogy of the microfine materials will dictate the changes that may occur within the concrete matrix [4].

In concrete, it is necessary to clarify the type and quantity of microfines as some types in small quantities can improve concrete qualities [4]. For example, literature has pointed out that the addition of microfines could influence the packing density (compactness) of concrete due to the improvement of the gradation of fine aggregates. This reduces the average pore size of cement-based material,

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which could improve the durability properties of concrete (see e.g., [5–7]). Microfines are also used in highly engineered concretes such as self-compacting concrete (SCC) and ultrahigh performance concretes (UHPC). The workability of SCC is enhanced as microfines act to fill the lower end of the gradation curve [8, 9]. In UHPC microfines could fill the aggregate-paste transition zone, increasing the strength of concrete [10].

On the other hand, literature also suggests some undesirable impacts of microfines in concrete. Microfines are primarily seen to reduce the workability due to their high surface area, which requires the water demand to increase, affecting strength and durability [2]. The biggest influence of microfines on mortar and concrete properties is on the water demand [3]. Water in concrete is as important as the binder itself as it influences both the fresh and the hardened concrete [11]. The reported negative impacts of microfines are rather due to is mineralogical composition, particularly when large amounts of silt and clay are present. Various studies, for example, report a decrease in compressive strength, an increase in drying shrinkage [2], and a decrease in consistency of cement-based mortar [12], among others. The negative impacts of contaminated microfines, however, can sometimes be averted with the use of admixtures such as superplasticizers to recover some consistency of concrete while maintaining the water-cement ratio (see e.g., [13]). However, superplasticizers may also exhibit sensitivity to clay impurities in fine aggregates, as in some cases the negative impact of clay minerals on the dispersing force of superplasticizers was very pronounced [14].

As such, due to the varying impacts of microfines in cement-based materials (particularly concrete), the amount of microfines in the concrete matrix is regulated. The American Society for Testing and Materials (ASTM) C 33 [15] specification, for example, set a limit as to the amount of microfines allowed in the concrete matrix. About 3-7% microfines can be included in the concrete mix, depending on the materiality of the microfines. A 7% maximum is allowed when the microfines do not contain any clay or shale. However, the limits set for microfines content in concrete could be undesirable as some fine aggregates contain surplus amounts of microfines. For example, in manufactured sand, microfines are typically as high as 10-20%, and removing the surplus microfines can be both uneconomical and environmentally damaging. Research has demonstrated that depending on the mineralogical properties of microfines, the limits outlined in various standards (i.e., ASTM C 33 [15], GB/T 14684-2001 [16] in China and others), could indeed be expanded (see e.g., [17, 18]). Nevertheless, this is still subject to the mineralogy of microfines, which is ultimately dependent on the source of fine aggregates. In other words, the properties of concrete could vary depending on the source of fine aggregates which contain the microfines.

This study, therefore, was undertaken to determine the influence of microfines on concrete performance when locally sourced fine aggregates containing microfines are used. Specifically, these aggregates are quarried from the Mandulog River system, in Iligan City, Philippines, which is one of the primary sources of aggregates around the northern Mindanao Region. While the extant literature on the topic is numerous, to the knowledge of the author this is the first local investigation on the possible effect on concrete properties of microfines present in fine aggregates quarried from the Mandulog River system. It is suspected that considerable amounts of microfines contaminated with clay and silt are present in the fine aggregates obtained from the site. These microfines could be attributed to the small-scale mining activities and deforestation upstream. In fact, in 2011, mining activities contributed to the mud which flowed downstream the Mandulog River system during the typhoon Washi [19]. In this vein, it is thus important to understand the influence of microfines contained in the quarried fine aggregates from Mandulog River on concrete performance.

The objective of this study is threefold: (1) to investigate the influence of varying amounts of microfines in the sand on the workability of concrete, (2) to examine the effect of varying amounts of microfines in the sand on the water demand of concrete, and (3) to determine the impact of varying amounts of microfines on the compressive strength of concrete. The result of this research could impact the mechanisms to which the local construction industry would assure concrete quality when fine aggregates contain microfine materials. Further, it could add to the existing body of knowledge in concrete science by elucidating the impact of fine aggregate sources on the microfines content of concrete and their effect on concrete quality.

2. Materials and Methods

The effects of microfines on the fresh and hardened properties of concrete were measured following the experimental design reflected in Fig. 1. Concrete mixes were prepared to contain varying amounts of microfines from 0 to 6% at a 1% increment of the mass of fine aggregates in the concrete mix as the independent variable. The experimental design was limited to only 6% following the limits found in ASTM C 33 [15] to confirm whether this suggested range of microfines content is acceptable for concretes produced using the fine aggregates from the Mandulog River system.

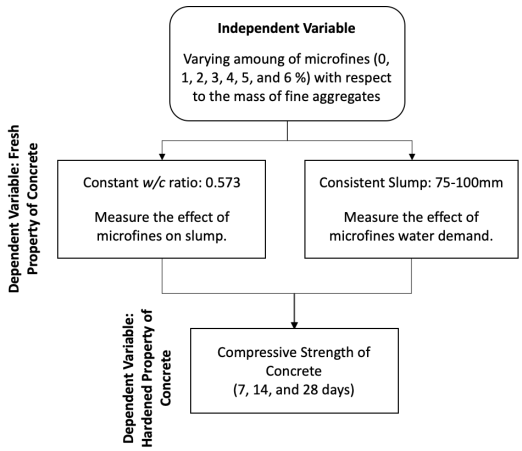

Figure 1. General experimental design of the research

The constituent materials used in this study have the following properties: the sourced fine aggregates from the Mandulog River system have a fineness modulus of 3.56, bulk specific gravity of 2.58, and absorption of 3.82; the coarse aggregates have a specific gravity of 2.76, absorption of 3.82, and with Saturated Surface Dry (SSD) Density of 2638.29 kg/m^3; the cement used conformed to Type I Ordinary Portland Cement (OPC) specification.

The aggregates, upon quality testing generally conform to the quality requirements of the ASTM C 33 [15], but have been observed to contain microfine materials. As such, to make a comparative analysis on the effect of the amount of microfines, the aggregates were sieved thoroughly using sieve No. 200 to separate the microfines (< 75 µm) from the aggregates. In addition, the aggregates were washed several times with water to further remove those microfines which adhered to the surface of the aggregates. This was done using a flowing water source until the effluent showed a clear appearance. The microfines obtained from sieving were reused in the mix following the desired amounts defined in Fig. 1. This is to replicate how river-quarried aggregates are directly used in concrete production by the local construction industry with almost no regard for microfines content. It is important to note that in this preliminary study, there were no further experimental tests done to confirm the mineralogy of the microfines used as to the amount of silt, clay, and other clay-sized particles in the microfine mix. However, the author recognized the importance of this mineralogy test, as the characteristics of microfines, particularly the amount of clay and clay-sized particles would also affect the performance of concrete (see [13]).

The concrete mix with 0% microfines acted as the control mix, which was designed to achieve the desired strength of 21 MPa with a slump of 75-100 mm. The proportioning of the control mix was decided following the ACI 211.1 [20] or the standard practice for selecting proportions for normal, heavyweight, and mass concrete. Tables 1 and 2 reflect the mix proportions of the concrete used for the experiment. The amounts of constituent materials shown in both tables were proportioned using a 1 cubic meter functional unit of concrete as standard mix proportioning method per ACI 211.1 [20] or the "*Recommended Practice for Selecting Proportions for Concrete*." Further, in Table 1, the notation WC indicates that a constant water-cement (w/c) ratio was used, and the number following it (i.e., in WC – 1) indicates the percent of microfines in the mix relative to the mass of fine aggregates.

Table 1. Mix proportions for concrete with a constant water-cement ratio

Mix	Mix Proportions (kg/m^3)				
	W	C	S	G	Microfines
Control	220.0	384.3	616.2	1152.0	0.0
WC - 1	220.0	384.3	610.0	1152.0	6.2
WC - 2	220.0	384.3	603.9	1152.0	12.3
WC - 3	220.0	384.3	597.7	1152.0	18.5
WC - 4	220.0	384.3	591.6	1152.0	24.6
WC - 5	220.0	384.3	585.4	1152.0	30.8
WC - 6	220.0	384.3	579.2	1152.0	37.0

Note: W (water), C (Cement), S (Sand), and G (Gravel).

Table 2. Mix proportions for concrete with consistent slump at 75-100 mm

Mix	Mix Proportions (kg/m^3)				
	W	C	S	G	Microfines
Control	220.0	384.3	616.2	1152.0	0.0
SL - 1	220.0	384.3	610.0	1152.0	6.2
SL - 2	220.0	384.3	603.9	1152.0	12.3
SL - 3	220.0	384.3	597.7	1152.0	18.5
SL - 4	218.0	384.3	591.6	1152.0	24.6
SL - 5	218.0	384.3	585.4	1152.0	30.8
SL - 6	218.0	384.3	579.2	1152.0	37.0

The mix proportions shown in Table 2, on the other hand, were obtained through a series of trial tests to limit the slump to a range of 75-100 mm, which was the desired slump for the control mix. The initial proportions used for the trial mixes were those found in Table 1 for the concretes containing varying amounts of microfines, and only the amount of water in the mix was allowed to vary. As such the amounts of cement, sand, gravel, and the amount of microfines remained the same as in Table 1. Additionally, in Table 2, the notation SL signifies a consistent slump, and the number following it indicates the percent of microfines in the mix. It is notable that in Table 2, only SL - 4, SL - 5, and SL - 6 have slight variations in the amount of water compared with their corresponding mixes in Table 1 to keep the slump of these mixes at the desired range.

The effect of microfines at the proportions studied in this research on the fresh properties of concrete were measured using slump (when w/c is constant) and the water demand (when the slump is in the range of 75-100 mm), as in Fig. 1. Additionally, the compressive strengths of concrete measured at 7, 14, and 28-day curing periods were used as an indicator of the effect of microfines on the hardened property of concrete. This research only used the compressive strength of concrete to measure mechanical properties as it is recognized as the most important indicator of concrete quality (see [11]).

The concrete samples were mixed according to ASTM C 192 [21] and were then tested for slump (fresh property of concrete) according to ASTM C 143 [22]. The concrete cube samples were water-cured by ponding and were then tested for compressive strength following the BS EN 12390 [23] standard at various curing dates, as in Fig. 1. In this study, however, instead of using 6-inch cube samples per BS EN 12390 [23], this study used 4-inch cube samples to minimize the use of materials. The author, however, recognizes the effect of cube size on the actual compressive strength, but this effect is less of a concern as it is more interesting to see the impact of microfine content in terms of strength development. Literature has shown that sample size may have less impact on the trend of strength development, allowing for the observance of the effect of microfines on the properties of concrete (see e.g., [24]). Besides, 4-inch cube samples are easy to handle, store, and consume a lesser amount of materials. In this study, 3 samples were tested for compressive strength for the control group and concretes containing microfines additions.

3. Results and Discussions

3.1. Concrete with constant water-cement ratio

By having the water-cement ratio constant, the effects of varying amounts of microfines on the properties of fresh and hardened concrete were measured in terms of the slump and compressive strength, respectively. Fig. 2 shows the effect of varying amounts of microfines on the slump of fresh concrete.

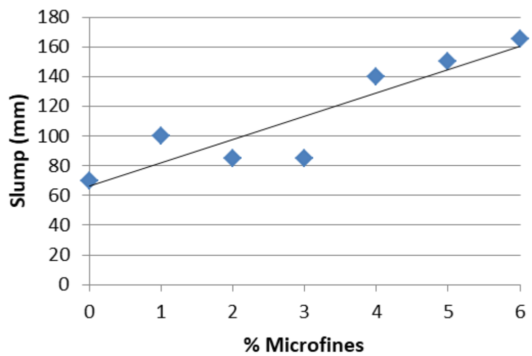

Figure 2. The slumps of concrete with varying amount of microfines at a constant water-cement ratio

From Fig. 2, it is apparent that, generally, the varying amounts of microfines in the concrete mix could affect the slump for a constant water-cement ratio condition. Further, a trend can be observed that as the amounts of microfines increase in the concrete matrix, the slump of concrete tends to increase in the range of microfines content considered in this study. This is particularly prevalent in the range of 4, 5, and 6% microfines additions. This effect could be explained by both the physical and chemical action of the microfines. In terms of the physical action, there may be an excess amount of mixing water due to the occupation of the voids of the aggregates by the microfines added, preventing water from entering these voids. In self-compacting concrete (SCC), as an example, microfine materials are used to enhance the workability as this could fill the aggregate-paste transition zone [2, 10]. This physical action, however, is less prevalent in the lower ranges of microfines additions (i.e., 1, 2, and 3%) as there are fewer amounts of microfines to occupy more voids in the aggregates. Thus, the slump essentially remained in the desired range based on the concrete proportioning method (75-100 mm).

The chemical action of microfines, on the other hand, could also affect the slump depending on the constituency of the microfines as this determines how microfines react with the presence of water.

For example, the presence of clay minerals in concrete has long been a concern as it can harm the properties of concrete because of its ability to absorb water, which increases the water demand [13]. Since the water-cement ratio was constant in this case, the slump should decrease if the microfines are composed mainly of clay minerals. However, the increasing trend of slump implies otherwise. Further, the increase in slump could be an indicator that a good proportion of the microfines' mineralogy could be hydrophobic in nature (e.g., less amount of clay mineral), and thus, will absorb less water, allowing the slump to increase. This is contrary to the assumption that microfines in fine aggregates are contaminated with high amounts of clay minerals. The mineralogy of the microfines, however, was not determined in this study and is subject to further clarification in future works.

In terms of compressive strength, Fig. 3 shows the effect of varying amounts of microfines on the compressive strength measured at 7, 14, and 28 days curing periods of concrete mixes having a constant water-cement ratio. Based on Fig. 3, the strength development of concrete mixes, irrespective of the amounts of microfines considered here, generally reflects similar strength development as the control mix. That is the strength increase with the curing time. Hence, it can be said that generally, the presence of microfines at the range considered in this study will not substantially affect the strength development of concrete. This could be because the strength development of concrete is primarily governed by the amount and the hydration of cement in the concrete matrix. Additionally, based on Table 1, the amount of microfines compared to the amount of cement is significantly lower; hence, the strength development is not affected.

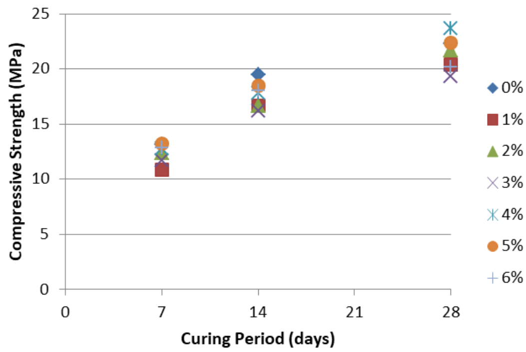

Figure 3. Compressive strength of concrete at various curing periods and with varying amounts of microfines for constant water-cement ratio condition

While the strength development of concrete mixes with varying amounts of microfines follows that of normal concrete, however, the values of the compressive strengths at various curing periods differ. This implies that the presence of microfines could affect the strength of concrete. To measure this effect statistically, the compressive strengths at the 28th-day curing period were compared. The 28th day compressive strength is appropriate for this purpose since the quality of concrete is often indicated by the compressive strength on the 28th-day (see [11]). As such, an analysis of variance (ANOVA) is carried out to test the differences between the means of the compressive strengths of concretes with varying amounts of microfines from 1 to 6% at 1 % increment. The ANOVA assesses the validity of two hypotheses: the null hypothesis (H_0) and the alternative hypothesis (H_1). In this analysis, the null hypothesis (H_0) for the ANOVA was that there is no statistically significant difference between the compressive strength on the 28th day of the control to that concrete mixes added with microfines for constant water-cement ratio condition. Conversely, the alternative hypothesis (H_1) posits that there is a significant difference. The ANOVA was executed using R software version 4.1.0 – a programming language for statistical computing – and the result is summarized in Table 3 for a 0.05 level of significance.

The p-value obtained from ANOVA is 0.160, which is greater than the specified level of significance of 0.05; hence the null hypothesis (H_0) is not rejected. This implies that all means of the compressive strengths on the 28th-day curing period of mixes with varying microfines and the control at a constant water-cement ratio condition are equal. In other words, for the ranges of microfines content considered in this study, the compressive strength of concrete would not be significantly affected. However, the author cautions that this finding is limited to the constituency of the microfines used in this study. A post hoc test (t-test) was not carried out, following the result of the ANOVA, as the means are equal.

Table 3. ANOVA result for compressive strengths at 28th-day curing period for concretes having constant water-cement ratio and varying amounts of microfines

Source	Sum of Squares	df	Mean Square	F	Sig, (p-value)
Between Groups	47.244	6	7.874	1.856	0.160
Within Groups	59.390	14	4.242		
Total	106.635	20			

The result of the 28th-day compressive strength test supports the range of microfines allowed in concrete matrix per ASTM C 33 when aggregates contain some amounts of shales and clays. Further, this result also naturally means that concrete produced using aggregates from the Mandulog River system can be allowed to have microfines content of up to 6% without a significant detrimental effect on the compressive strength of concrete.

3.2. Concrete with consistent slump at 75-100 mm

The effect of microfines content on concrete performance was also measured in terms of water demand and the corresponding effect on compressive strength, by setting the slump of fresh concrete to a consistent range between 75-100 mm. Fig. 4 summarizes the effect on the water demand.

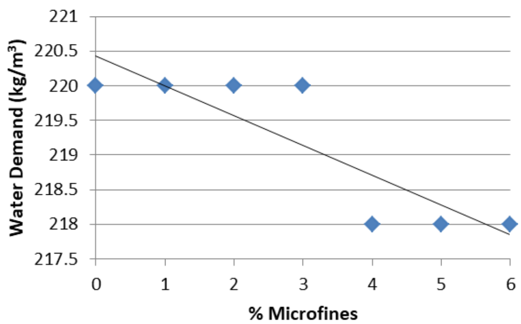

Figure 4. Water demand of concrete mixes with varying amounts of microfines with slump set to 75-100 mm

From Fig. 4, it is notable that the water demand on concrete is affected when varying amounts of microfines are introduced into the concrete matrix. In particular, the water demand seems to reduce at higher additions of microfines (i.e., in the range of 4, 5, and 6%); whereas, it remained essentially the same for lower ranges of microfines addition. This result could again be attributed to both the physical and chemical action of the microfines. As pointed out in Section 3.1, the occupation of voids of the aggregates by the microfines could be one potential reason attributable to the physical action of microfines. In the 4, 5, and 6% microfines content, there is a reduction in water demand because the voids on the surface of the aggregates might have been occupied by microfines, thus requiring less water to retain the slump at the 75-100 mm range. This result remains consistent with the effect on slump when the water-cement ratio was kept constant. The same physical action could be associated with the microfines content in the range of 1, 2, and 3%, where there is essentially no change in water demand, as the amount of microfines occupying the voids on the surface of the aggregates is still in a small amount, hence the water demand remained as is.

The chemical action of microfines could also be attributed to the result in the reduction of water demand, as this reduction could be an indicator that a good proportion of the microfines could be exhibiting a hydrophobic behavior, thus microfines will absorb less amount of water. Again, the constituency of the microfines, however, was not measured in this study and will form part of future research work. Nevertheless, this result is indicative that chemical action is an important property of the microfines, particularly when higher amounts of microfines are added to the concrete matrix.

In terms of the compressive strength, Fig. 5, shows the effect of varying amounts of microfines when the slump is set to a consistent range (75-100 mm). From Fig. 5, it remains apparent that the strength development of concrete is not affected by the addition of microfines at the ranges considered in this study. That is, the strength development – increase in compressive strength with curing days – of concrete mixes with microfines reflects a similar trend as the control mix.

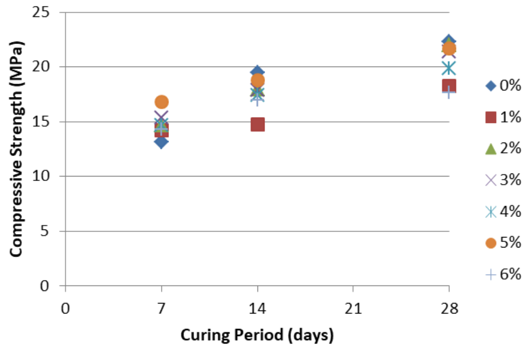

Figure 5. Compressive strength of concrete at various curing periods and with varying amounts of microfines for consistent slump condition

However, in terms of the actual values of compressive strength at the curing periods considered, Fig. 5 further exhibits that the compressive strengths differ for the amounts of microfines in the concrete mix. This is particularly true for the compressive strengths at the 28^{th}-day curing period, which was considered as one important indicator of the concrete quality. To clarify if this difference in compressive strengths is statistically significant, an ANOVA was again carried out using R software version 4.1.0. The 28^{th}-day compressive strength was again used for ANOVA for the same reason stated in the previous subsection. For this analysis, the null hypothesis (H_0) for the ANOVA enunciates that there is no statistically significant difference between the compressive strength on the 28^{th} day of the control to those concrete mixes added with microfines when the slump was kept at a consistent range of 75-100 mm. Conversely, the alternative hypothesis (H_1) for the ANOVA posits that there is a significant difference. Table 4 presents the ANOVA result for a 0.05 significance level.

Table 4. ANOVA result for compressive strengths at 28^{th} day curing period for concretes controlled to have a slump of 75-100mm and with varying amounts of microfines

Source	Sum of Squares	df	Mean Square	F	Sig, (p-value)
Between Groups	52.177	6	8.696	1.448	0.265
Within Groups	84.095	14	6.007		
Total	136.272	20			

From the ANOVA table, the computed p-value is 0.265, which is greater than the 0.05 level of significance considered; thus, the null hypothesis (H_0) is not rejected. This result implies that the means of the compressive strength of concrete mixes with varying amounts of microfines and the control, when the slump was kept at a consistent range, are not statistically different. What this means for the local construction industry, especially those using aggregates from the Mandulog River system in Iligan city, is that up to 6% of microfines content can be allowed in the concrete matrix without significantly affecting the compressive strength. This range of microfines addition conforms to the limit set by ASTM C 33 [15] for aggregates containing shales and clays. The effect of microfines, however, on the other performance of concrete must be further investigated.

4. Conclusions and Recommendations

This study investigated the influence of microfines in the sand on concrete performance by using locally sourced fine aggregates from the Mandulog River system in Iligan City, Philippines. Through experimentation, it is found that the slump of concrete is affected with the addition of microfines content at the range considered in this study, but remained at an acceptable level. The slump of concrete increased as the amount of microfines was increased, which could be attributed to both the physical (i.e., the occupation of the surface voids of aggregates by microfines) and chemical action (i.e., microfines could be less contaminated with clay or silt materials) of the microfines in the concrete matrix. The water demand for concrete, on the other hand, was affected by the addition of microfines content at the range investigated in this study. The water demand seemed to decrease when the amount of microfines increased. This result could also be attributed to the physical and chemical action of the microfines present in the concrete matrix. Finally, the compressive strength of concrete on the 28^{th}-day curing period was not significantly affected by the presence of microfines in the concrete matrix at the range considered in this study. This is true for conditions when the water content was constant and when the slump was controlled to a consistent range of (75-100 mm) while microfines are added from 1% to 6 % at a 1% increment of the mass of fine aggregates. Therefore, when only considering compressive strength, up to 6% of microfines can be allowed in a concrete mix when aggregates from the Mandulog River system, in Iligan City, Philippines are used. The findings of this study suggest that various sources of fine aggregates must undergo quality tests to determine the effect of microfines on concrete properties so a range of allowable microfines in concrete concerning the source can be defined clearly. However, a considerable portion of this research needs further clarification, particularly the mineralogy of the microfines used in the experiment. It is thus recommended to further study the mineralogy of the microfines and to see if the range considered in this study could be expanded beyond the limits of ASTM C 33. Finally, additional concrete properties, particularly those that are relevant to durability must also be considered in future research work.

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