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Investigation of Compressive Strength of Rubberized Concrete Improvised with Silica Fume

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KEYWORDS

Rubberized concrete
Silica fume
Compressive strength

ABSTRACT

The disposal of waste tyres has become a major environmental issue due to the massive volume produced globally. Due to the economic and environmental benefits, it appears that recycling discarded tyres was the most effective way of disposing of these materials. This investigation was carried out to find the compression strength of rubberized concrete improvised with silica fume. The percentage of crumb rubber that has been used in the investigation was 0%, 10% and 15%, with 4% of silica fume. The result from experiment shows that as the proportion of the crumb rubber increases, the compressive strength of rubberized concrete samples is decrease. However, the compressive strength is improved with additional of silica fume as replacement of cement. It can be concluded that the rubberized concrete with silica fume able to produce comparative strength as good as conventional concrete.

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1. INTRODUCTION

The accumulation obtained from waste tires has been a major source of worry since the scrap rubber is not easily biodegradable, even after long-term landfill treatment. Nevertheless, material and energy are possible solutions to waste rubber recycling. Several investigations recommended using it as a fuel or as a raw resource for rubber products, but on the other side, a broad range of waste materials have been proposed as an alternative concrete material additions. As a way of reducing the waste rubber, it can be used as an alternative to the fine aggregates in the structural concrete elements.

The use of waste rubber in concrete gives positive impact on the environment, society as well as construction industry. Waste rubber, as is generally known, is not easily biodegradable and requires a lengthy time of landfill treatment to be disposed. However, the study [11] proved that the recycling of leftover rubber by combining it with concrete contributes significantly to landfill reduction. The added advantage might help to reduce landfill pollution by contaminating soil and water with hazardous and liquid substances from discarded tires.

At the same time, the application of rubberized concrete might give significant drawback in terms of strength performance. In order to overcome the weakness, previous studies [1, 3, 4, 7, 8] have proposed the incorporation of pozzolanic materials as an addition or replacement in concrete mixture. The fine and condensed particles of silica fume, fly ash and other pozzolanic materials able to occupy the voids in concrete mixture, enhance the bonding and help to increase the strength.

1.1 Rubberized concrete

The incorporation of rubber in concrete mixture has been a major interest in concrete field of research. As stated in the aforementioned studies, the rubberized concrete is produced as an alternative to the lightweight concrete. However, there is also weakness in the compressive strength with the increasing content of rubber crumb. As studied [18], the rubber aggregate is combined in the concrete mixture with cement, fine and coarse aggregates, sand, and water, as well as super plasticizers and additives. The results show that the mix has acceptable consistency, but the compressive strength decreases as more

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rubber is added. According to the paper, lower rubber mixes with higher compressive strength can be utilized for structural applications, while lower compressive strength and volume mixes could be used for non-structural elements.

Several studies have been conducted to explore the influence of waste tire rubber on concrete strength. A study [2] has conducted an experiment on concrete mixtures including 3.5% to 5% of rubber by volume, as well as additional additives. According to the results of the tests, the compressive strength of rubber plastic was 23 MPa, while the other samples without rubber particles was 36 MPa. Rubber filled samples revealed not just a loss in compressive strength, but also in density, and modulus of elasticity when tested using a multiple bending strength and multiple static bending load techniques.

Similarly, study [16] has found that the compressive strength of the concrete employing scrap tire rubber was much lower than that of conventional concrete. However, the study discovered that utilizing of the crumb rubber rather than chipped rubber greatly boosted the compressive strength. Concrete made from discarded tire rubber, on the other hand, displayed substantial ductility. Further agreement was obtained [6], where the study has found that the compression test carried out shows the compression strength is decreased as the percentage of the chip rubber increase. Even though the increasing in the quantity of tire rubber used to substitute coarse material has improved the workability. This finding also supported by the previous experiment [5] where the result of experiment shows that the addition of the crumb rubber in concrete basically contribute to the lower strength, even high ductile failure. As investigated [15], the losses of strength is happening because of the shortage of adhesion between the cement and the rubber particles.

There are various studies investigated on the pre-treatment of tire rubber aggregates to enhance the adhesion of aggregate and cement paste. These criteria are important as to ensure the concrete block is much good in strength. One of the ways of treating the tire rubber is immersing in sodium hydroxide. According to the study [3], when the rubber aggregates have been pre-treated in the sodium hydroxide, it shows an improvement in flexural strength, water content, and fracture energy. At the other side, a small reduction in the compressive strength has been identified.

The research on shredded rubber in concrete mixture and its advantageous have been examined [17]. The paper has stated that the replacement of aggregate with the crumb rubber is basically not a good idea for structural members because it shows a large amount of reduction in the strength, especially for more than 20% of replacement in aggregate. This mixture reduces drying shrinkage and brittleness while enhancing the elastic module, extending the service life of such blends. Because strength is crucial, and any drop in compressive strength might be fatal, rubber mixture concrete must not be utilized for loading elements such as columns and beams. Rubber mixture concrete, on the other hand, is more suitable for non-structural construction work.

1.2 Silica fume in Rubberized Concrete

In order to solve the weakness of rubberized concrete, a numerous studies have been conducted especially to improve the compressive strength of rubberized concrete. This including the incorporation of pozzolanic materials as cement replacement in concrete mixture. The pozzolanic materials such as fly ash, silica fume and metakaolin are usually added to provide "glue" or adhesion in between cement, water, fine aggregate and coarse aggregate.

Earlier, a study [4] on the construction of rubberized concrete mixes containing with and without silica fume was conducted. Two types of rubber have been used for comparison, which are crumb rubber and rubber chip. The fine and coarse aggregates were replaced with the rubber aggregates with a different volume, as well as different volume of silica fume as replacement of the Portland cement. From the result, there is a reduction in compressive strength when the volume of the rubber content increases. By having an optimum volume of rubber content and silica fume, it is able to identify that there is an increase in the compression strength. The study has concluded that the silica fume is a finer particle which able to act as filler in the concrete mixture and create a good bonding between the cement paste and the aggregates. The density of concrete increases as well as the compressive strength.

Due to the improvement in compressive strength, further investigation [18, 7] were carried out on the influence of silica fume in the rubberized concrete. A research was conducted by [18] on high-strength lightweight concrete. The experiment was carried out by using lightweight aggregate to produce concrete density less than 1860 kg/m^3. Various content of silica fume has been used in the experiment as well as water-cement ratio. According to the finding, the ideal content for silica fume replacement to achieve the maximum 28-day compressive strength of lightweight high strength concrete varies from 15% to 25%, relying on the mix's water-cement ratio. The result shows the maximum compressive strength is achieved at 20% of silica fume content with water-cement ratio 0.3.

Followed by [7], the investigation has shown a substantial improvement in the compressive strength of concrete due to the obvious strong pozzolanic activity and void filling capacity of silica fume. The pozzolanic reaction turns the weaker calcium hydroxide crystals into the strong calcium silicate hydrate gel in the chemical stage. Similar agreement has shown by the result [20], the utilization of silica fume gives significant development in the compression strength of the concrete. The reason of reduction in rubberized concrete strength is because a poor link between rubber and cement, which restrict the growth of concrete with a large rubber component. Other than that, strong argument was summarized by [1] where the study has discovered that using silica fume in rubberized concrete mixes not only decreases the quantity of cement used but also boost the compressive strength, dynamic and static moduli, and flexural modulus. The crumb rubber in concrete barrier sample shows a higher value of impact resistance, durability, ductility, and also good toughness.

Significantly, the compressive strength of the rubberized concrete cube was enhanced gradually with the increased silica fume quantity, and silica fume significantly boosted the compressive strength of concrete during the curing phase. Studies by [8, 21] have agreed that the nano-silica has increase the porosity and pore refinement, reinforce the interface transition zone, and promote adhesion, therefore partially minimizing the strength reduction of rubber concrete. When water is mixed to the cement mixture and the silica fume, the cement first will dissolve in the water, and SiO_2 in the silica fume reacted with $Ca(OH)_2$ precipitated in the hydrated cement to produce the calcium silicate hydrate colloid, which is stuffed the voids areas around the hydrated cement particles and enhanced the compressive strength of the rubberized concrete. For practical and economic reasons, silica fume seems to be the best option.

Based on this promising improvement in [4, 7, 8, 18, 21], it is an intention of this current study to investigate the compressive strength performance of rubberized concrete incorporating silica fume as cement replacement, in a lower volume. This study has focused to investigate the progression of concrete 0% to 15% replacement of rubber in fine aggregate, improvised by 4% of silica fume.

2. EXPERIMENTAL WORK

The objective of this research is to determine the compressive strength of rubberized concrete, improvised by silica fume as the partial replacement of cement. The material that is going to be used in this experiment is cement, water, fine aggregate, coarse aggregate, silica fume and crumb rubber. The laboratory test is conducted to investigate the fresh and hardened concrete cube properties as well as workability test. For the mechanical properties compression test was carried out.

2.1 Material Preparation

This experiment involved the usage of fresh Ordinary Portland Cement OPC. The river sand which is free from any organic or inorganic components is used as the fine aggregate. The sand is sieved through a mesh size of 2.36mm until it reaches a particle size of 150 microns. The course aggregate used in the mixture contains gravel stones size of 20mm. Tap water was utilized throughout this study.

In this investigation, granular crumb rubber was used and sieved to obtain 6mm size. The silica fume was bought from private company, MC Fiberglass & Hardware Supply. The silica fume was gone through the sieve with opening of 600 micrometre and was kept in an air tight container in order to prevent any moisture from the surrounding.

2.2 Concrete Mix Proportion

A total of four batches of concrete mix is prepared in order to observe the improvement of compressive strength of rubberized concrete. Table 2 below shows the mix proportion of the concrete in weight, Kilogram. M1 represents the control mix, which consists of 0% of rubber, designed according to M20 strength. The second and third mix; M2 and M3 were prepared by replacing 10% and 15% weight of fine aggregate with crumb rubber respectively. While the fourth mix, M4 was prepared by replacing 15% of fine aggregate with crumb rubber and 4% weight of cement with silica fume.

Table 1. Concrete Mix Proportion

Mix Type	Water	Cement	Fine aggregate	Coarse aggregate	Silica fume	Crumb rubber
M1	7.02	12.81	14.5	39.15	-	-
M2	4.68	8.54	8.7	26.1	-	0.97
M3	4.68	8.54	8.21	26.1	-	1.45
M4	7.02	12.3	12.32	39.15	0.51	2.17

There were total of nine samples were prepared for each mix of M1 and M4. Meanwhile, six samples were prepared for each mix M2 and M3. The number of samples differentiated by curing days, where M1 and M4 were observed for 7, 14, and 28 days of curing, while M2 and M3 were observed for 7 and 28 days of curing.

2.3 Instrument and Test Procedure

The experimental works were done in concrete lab, Manipal International University, Nilai. In order to assess the particle size distribution of fine and coarse aggregate, the sieve analysis was conducted in accordance with BS 812103:1:1985. The aggregates were sifted by using the mechanical sieve shaker as shown in Figure 1. The coarse aggregate used went through a 20 mm filter.

Fig. 1. Sieve Analysis

All the materials were mixed properly as per proportion. A slump test is conducted to determine the workability of rubberized concrete. The concrete mix is placed properly inside the slump cone by three equal layers. Each layer is tamped 25 times by using metal rod. The slump cone is then lifted up, and the height of slump is measured. Figure 2 shows the measurement of slump after cone is lifted.

Fig. 2. Measurement of slump height

For casting, the concrete mould in cube size; 150mm x 150mm x 150mm was used. The moulds were cleaned before use to ensure free of concrete leftovers prior operations. Thereafter, the moulds were coated with grease before filled with the concrete. The casted specimens were let to harden for 24 hours in environment temperature. The specimens were then demoulded and kept submerged in the curing tank for 7, 14 and 28 days.

After completion of curing day, the specimens were taken out from the tank and then wiped from excess water. The specimen is placed centrally on the base plate of the machine. The remaining height is adjusted until it touches the concrete surface. Figure 3 depicts the compression machine and the location of the concrete cube prior to the application of force. The compressive strength test was performed by using compression machine (200T 2000kN Digital Display). Load is applied gradually and continuously until the samples fails. The maximum load achieved is recorded and the compressive strength, f_{ck} of respective specimen can be calculated by dividing the maximum load applied, P (Newton) with cross sectional area of the cube, A (millimetres square). The formula can be written as follow:-

$$f_{ck} = \frac{P}{A} \tag{1}$$

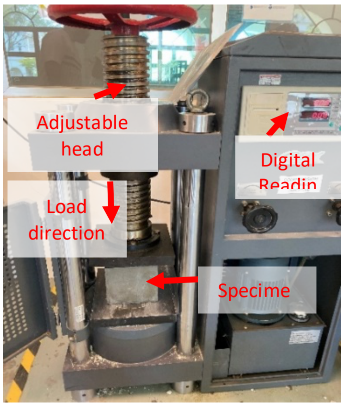

Fig. 3. Compressive Test

3. RESULTS AND DISCUSSIONS

In this study, various percentages of crumb rubber were mixed in the concrete mixture to investigate its compressive strength. An adequate percentage crumb rubber and silica fume were then mixed in order to show the improvisation in the compression strength. All the concrete samples were cured in water for the 7, 14 and 28 days before the testing. The discussion of the obtained data is explained below.

3.1 Workability of Rubberized Concrete

The slump test was conducted to measure the workability of fresh concrete for both control samples and rubberized concrete samples. The result of the slump test for the specimens were illustrated in the graph of Figure 4. The slump value for control samples and rubberized concrete samples were measured as 57mm, 54mm, 52mm and 50mm as per mix order. It is observed that the slump value decreasing as per increasing in replacement of crumb rubber in the mixture. Followed by replacement of silica fume in M4 samples, the slump value continuously decrease. The data has shown that increasing the rubber component in the concrete with additional silica fume has produced stiffer and less workable mixture. This was reflected by the significant decrease in slump value as shown in the graph. This result also consistent with the previous study [11] where the similar trend of decrement in slump value has shown for rubberized concrete.

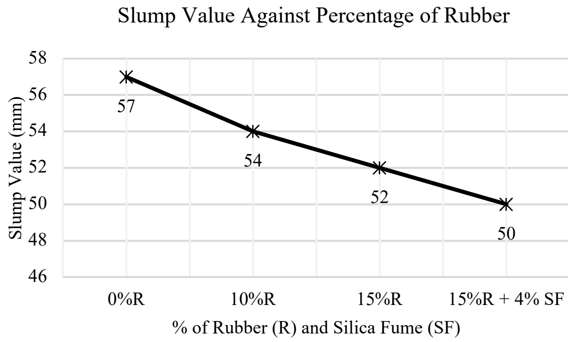

Fig. 4. Result of Slump Test

3.2 Compressive Strength

A total of 4 batches of concrete mixtures were produced with the various percentage of crumb rubber ranging from 0% until 15% and 4% of silica fume. The average data was calculated to get the high accurate and consistent results. In this investigation, a total of 30 concrete cube samples were casted and cured for compressive strength test. The first 9 samples are known as the conventional concrete specimen. Then the next 12 cube sample were mixed with the different percentage of crumb rubber replacement. Then the last 9 cube samples were made of partial replacement of crumb rubber and silica fume. The compressive strength was calculated by dividing the maximum load applied on the cube sample by the contact surface area. The average compressive strength of the specimens was compared and illustrated in the form of bar charts.

Figure 5 shows the comparison of compressive strength of samples cured in 7 days. The compressive strength of control samples (0% rubber) was recorded as 18.3 MPa (Mega Pascal), however decreases to 16.2 MPa once the 10% of crumb rubber has been added. The result is continuously decreasing to 15.9 MPa when 15% of crumb rubber is replaced in fine aggregate. This is continued by 15% of replacement. The decreasing trend shows the lack of bonding between the cement and the aggregate as it has been replaced by the crumb rubber, giving more voids in the mixture. As the silica fume is added for the replacement of cement, the compressive strength has improved much better than the other mixtures, showing 16% of increment when it is compared to the control specimen. This basically shows a positive start for the 7^{th} day compression test data where the silica fume actually works as creating a good bonding between the cement and also the crumb rubber.

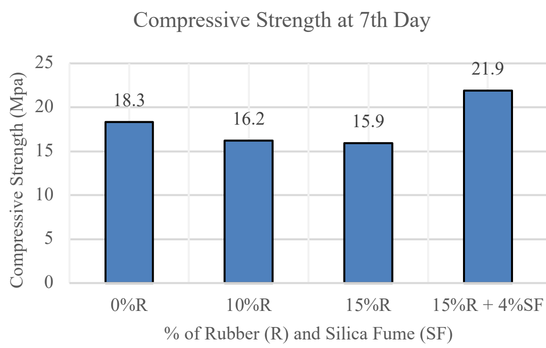

Fig. 5. Compressive strength at 7^{th} day of curing

Compressive test is then conducted at 14th days of curing, however only for batch M1 (0% rubber) and M4 (15% rubber and 4% silica fume) for observation purpose. The compression test is compared between these two batches and observed that all the control samples gain an increment individually as shown in Figure 6. Similarly for rubberized concrete with silica fume, the compressive strength for each samples increasing up to 32.8 MPa. Averagely, the compressive strength for these two batches was calculated as 28.3 MPa and 32.6 MPa for M1 and M4 respectively. This basically shows an increment about 49% to 55% in both samples as compared to the result in 7 day of curing. It is clearly understand that the compressive strength is increasing as the curing days increased.

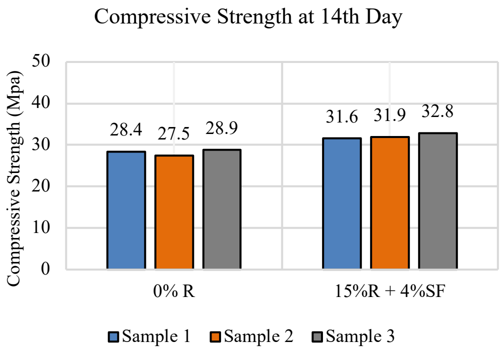

Fig. 6. Compressive strength at 28th day of curing

The compressive strength of all mixture is then compared at the 28th day of curing. At this age of curing, the compression strength represent the matured strength of concrete. As shown in Figure 7, an individual increment of compressive strength was observed in each mixture. At 28 days of curing, the compressive strength has increasing to 31.8 MPa for control sample, satisfying the target strength of normal concrete. Followed by M2 and M3, compressive strength were calculated as 29.5 MPa and 28.2 MPa respectively. The compressive strength of these mixture was clearly reduced compared to the control samples of M1 as more replacement of rubber was added into the mixture. However, improvisation was clearly noticed where the compressive strength is greatly improved from 28.2 MPa (M3) to 39.1 MPa with replacement of silica fume in M4.

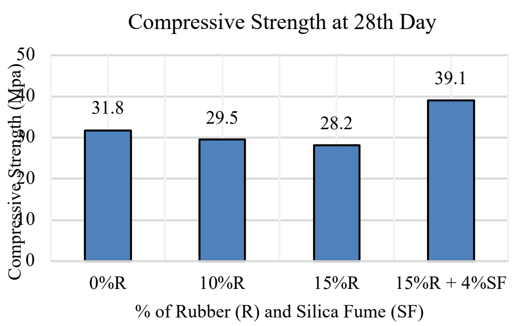

Fig. 7. Compressive strength at 28th day of curing

From the experiments, the comparison between early (7 days curing) and matured (28 days curing) compressive strength achieved by the concrete specimen can be made. The conventional concrete gives an early strength of 18.3 MPa which is about 8% higher than the 10% and 15% rubberized concrete. The trend has shown the reduction of compressive strength when rubber content is added as the replacement of fine aggregate. The rubber particles created void in the concrete mixture and weakening the bonding in concrete mixture. This has proved in the previous study [14], where the inclusion of crumb rubber in concrete reduces mechanical strength because the adhesion forces between the cement paste and crumb rubber particle boundaries gradually decrease, creating an increase in the volume of the interfacial transition region.

As predicted, the addition of the silica fume in the rubberized concrete improvise its mechanical characteristics and hence increase the compressive strength. During the initial period (7 days), it is observed that the rubberized concrete with silica fume able to withstand more compression strength than the conventional concrete, 21.9 MPa compared to 18.3 MPa. This has continuously observed in 14th day and 28th day of curing, in which the compressive strength is achieved as 39.1 MPa, 23% higher than control samples at matured age of curing.

The silica fume basically improve the properties of concrete by improving the bonding and compactness of the concrete mixture. Such argument has been supported by previous studies [3, 4, 13] where the utilization of silica fume in the cement mixture of the rubberized concrete able to improve the compressive strength and attained 90% of the conventional concrete compression strength.

4. Conclusion

The experiments are conducted to investigate the substitution of fine aggregate in concrete by crumb rubber, and silica fume is replaced at the optimal proportion in cement to increase its mechanical properties.

4.1 Summary

There are several conclusions that can be made from this study. The usage of crumb rubber in the concrete mix is particularly advantageous to the construction and environmental as to solve the issue of waste tyre rubber disposal all over the world. The implementation of crumb rubber in concrete helps to reduce the usage of natural aggregate and produce lightweight structure, which will be beneficial in terms of handling and cost.

Despite of reduction in strength, the utilization of silica fume in cement has positively solve the issue. It has continuously helped to improve the compressive strength in 7th, 14th, and 28th day of curing. With the optimum usage of 4%, the silica fume is sufficiently act as a binding material in the rubberized concrete. Due to its tiny particles, it is able to occupy the voids in between the crumb rubber in the concrete mixture, and then improve the compactness of the mixture. As the result, the bonding in concrete mixture is improved and able to withstand more compressive load. It can be concluded that the rubberized concrete with silica fume able to produce comparative strength as good as conventional concrete.

4.2 Recommendations

Several suggestions are provided below for the small scale of study in future.

- Other than compressive strength, the effects of varying amount of crumb rubber can be investigated on other parameters like sound insulation, thermal conductivity, impact, and water absorption.
- It is suggested that a future investigation can be carried out by comparing the silica fume with other type of pozzolan materials as aggregate replacement in rubberized concrete.
- Literature studies are suggested to explore the potential of rubberized concrete in other fields, other than structural application.

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