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Research Article

Evaluating the Mechanical Properties of Self-Compacting Concrete with Rubber Additives (Case Study: Shiraz Mind)

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Abstract

The use of rubber crumb as an additive in the production of concrete has been studied as a means of improving compressive strength while also addressing the environmental impact of non-degradable ingredients. In this research, the effects of adding 5%, 7.5%, and 10% rubber crumb by weight to 2% cement were analyzed. The results showed that the addition of 5% rubber crumb resulted in the highest increase in compressive strength, with a 45% increase at 7 days and 8% increase at 28 days compared to the control concrete. However, the addition of 10% rubber crumb resulted in a decrease in compressive strength, with a 3% reduction at 28 days, 5% reduction at 90 days, and 1% reduction at 120 days. The price of self-compacting concrete also increased by 16.4%, 20.5%, and 24.5% for the 5%, 7.5%, and 10% rubber crumb samples, respectively. Overall, this research suggests that the use of rubber crumb as an additive in concrete production can potentially improve compressive strength while also contributing to environmental sustainability, though the optimal percentage of rubber crumb for this purpose may vary.

Keywords:

Compressive Strength, Self-Compacting Concrete, Rubber Crumb, Permitted Additives Reasoning

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1- Introduction

Over the past two decades, there has been a growing focus on the use of urban waste materials in the construction industry. Many studies have been conducted to examine the benefits of incorporating recycled materials into construction products, as it can have positive impacts on both the environment and the properties of the final products. However, the waste materials produced by various industrial processes continue to pose significant challenges for both developed and developing countries, as research focuses on finding ways to recycle or dispose of these materials in a way that minimizes environmental damage.

One type of concrete that has received particular attention is self-compacting concrete (SCC). This type of concrete is known for its high fluidity and the ability to consolidate without the use of external energy sources. It also has the ability to flow easily between rebars and reinforcements, making it an attractive choice for construction projects. There are several advantages to using SCC, including faster construction times, reduced labor requirements, improved durability due to lower permeability, and greater design flexibility. However, using certain filler additives in SCC can alter the properties of the air-filled pores within the concrete, potentially impacting its stability during transportation. Researchers have found that using superplasticizers can increase the polymerization in the primary chain, which can help to reduce the setting time of SCC. However, it can also lead to the formation of larger volumes of air bubbles with diameters above 0.5mm and a decrease in the stability of the air bubbles within the concrete during transportation.

Figure 1: Recycled rubber powder for recycling [3]

According to Assad and Khayat (2002), the number of aerobic additives needed to create a certain amount of air (6+1.5%) is significantly higher in aggregates that contain viscosity-modifying additives compared to other aggregates. This effect is more pronounced in aggregates with lower dispersion rates, as determined by the slump flow test. Hadiyan and Sohrabi (2019) found that increasing the internal pressure of air bubbles leads to an increase in their solubility in aqueous solutions, resulting in a reduction in bubble size and overall amount of air in the concrete.

Sidic and naik (2004) studied the impact of various mineral additives on the properties of self-compacting concrete. They found that the use of slag had a significant effect on the efficiency of self-compacting concrete, and that it was possible to use aggregates with high replacement percentages of slag (up to 60% of the cement weight) while still achieving acceptable properties in both the fresh and hardened forms of the concrete. Li et al. (2004) conducted experiments on cement paste to create self-compacting concrete and found that substituting up to 10% of the cement volume with silica soot increased yield stress but had different effects on plastic viscosity depending on the type of superplasticizer used (it decreased with polycarboxylate superplasticizers and increased with naphthalene superplasticizers). Rubber is one of the novels recycled materials used in the concrete industry. In order to solve the crisis of reusing many recycled rubber materials, their use in the concrete industry has been offered as a possible solution (hong et al., 2004). In recent years, one of the essential research projects started on the properties of hardened concrete is the study of the hardened concrete's properties under high temperatures. Generally, the concrete's strength, especially under pressure, depends on the quality of the paste and granular as well as the latter's stiffness and density. Therefore, it can be stated that using rubber microparticles or powder can be a promising solution as it does not interfere with the paste's viscosity and strength. Researchers have been seeking ways to determine the proper coefficients of crumb rubber's size and volume in concrete to compare them with ordinary self-compacting concrete, thereby investigating the effect of the crumb rubber's size and volume on the self-compacting concrete. During the past 20 years, the usability of various kinds of urban wastes in the construction materials industry has been highly focused on, and many studies have been carried out in this regard. In many cases, the addition of recycled materials has been found to have many benefits for environment conservation and simultaneously sound effects on the properties of the final products. On the other hand, in the present era, the waste materials produced in various physical and chemical processes have become one of the critical problems of industrial and developing countries for fact that much extensive researches have been done on methods of recycling or dumping waste materials, thereby to minimize the environmental damages (naik, 2018).

The use of polyurethane paint was found to reduce the slump flow of self-compacting concrete containing metakaolin and microsilica, compared to the control specimens. The addition of nano-cupper made this reduction in slump flow more pronounced. In addition, when nanomaterials were added, the slump flow increased after a 10t pass period, with the increase being more significant in plots using nanocupper. Overall, the inclusion of nanomaterials in self-compacting concrete slowed the pass time through the funnel, with the effect being more pronounced in specimens containing nanocupper. However, the use of microsilica and metakaolin also increased the pass time in all specimens. In the l.box test, the pass time decreased in all specimens with nanomaterials, with the greatest reduction occurring in the plot using nanocupper at 3%. In general, the addition of nanomaterials to self-compacting concrete reduces its efficiency.

The compressive strength of all specimens increased with age, compared to the control specimens. The inclusion of nanosilica preserved this increasing trend, with the greatest increase occurring at a 2% nanosilica content. The inclusion of nanocupper also increased compressive strength, with the steepest slope and highest strength occurring at a 3% nano copper content. However, at 3% each, nanosilica and nanocupper both reduced compressive strength in 30-day-old concrete specimens compared to the control specimens. In general, nanosilica increases compressive strength, with the effect being stronger at higher nano silica content, while the same trend is observed for nanocupper but with a steeper slope.

In ultrasonic tests, the inclusion of 2% nanosilica increased the UPV of specimens. An increase of 33% nano silica led to a reduction in UPV. The addition of nanocupper to all specimens reduced UPV compared to the control specimens. The use of polyurethane paint also reduced the velocity of waves passing through all constructed specimens, with the difference in wave percentages increasing with the age of the concrete. Nanosilica and nanocupper both reduced water absorption in 21- and 30-day-old concrete specimens, with nanocupper having a greater positive effect on water absorption in 21-day-old specimens. However, at 30 days, nanocupper and nanosilica had similar effects on water absorption. The addition of polyurethane paint significantly reduced water absorption, with some specimens experiencing a reduction of 80% compared to unpainted specimens.

The infiltration of chlorine ions into specimens containing nanosilica and nanocupper was reduced, and the strength of concrete against infiltration increased with age. The effect was stronger for specimens containing nanocupper than for those containing nanosilica. The inclusion of polyurethane paint also reduced the infiltration of chlorine ions, with the greatest reduction occurring at a 2% nanosilica content. The results of this study suggest that the use of nanomaterials, particularly nanocupper, can improve the mechanical properties and durability of self-compacting concrete.

However, the effects of different nanomaterials and their content percentages should be carefully considered to achieve optimal results.Cement-to-water ratio is one of the primary factors influencing the efficiency, strength, durability, and other properties of fresh and hardened concrete. This ratio is in reverse relationship with strength and durability but directly with efficiency. However, water to cement ratio can be reduced to a certain amount, especially when making self-compacting concrete, for which the ratio should be huge. However, when it comes to high-performance concrete, the ratio should be brought down to the maximum possible extent to increase its strength and durability. On the other hand, in self-compacting concrete types, the viscosity of the paste should be intensively high. An increase in the paste's viscosity can be secured by using large amounts of power materials and chemical additives to modify the viscosity. The use of the powder materials also causes an increase in the specific surface area of the microparticles and micro granules, hence increasing the amount of water needed. Based thereon, the water-to-cement ratio should be changed regarding the water to the adhesives. Since the ratio of water to the adhesives is decreased a lot in the high-performance self-compacting concrete compared to the ordinary concrete, it is necessary to compensate for the fluidity (consistency) by increasing the amount of the used superplasticizers (generally polycarboxylates) to a large amount.

The density is the other parameter that influences the permeability and strength of the concrete and can minimize the amount of needed water. So, the higher the density is increased, the distribution of the aggregate particles and the powder particles would be in such a way that they occupy larger spaces; hence the water demand, the concrete's permeability, and bleeding would be reduced. Since the volume of the required paste is reduced subsequently, the efficiency and fluidity of the concrete would be increased considering a fixed amount of paste. Thus, density maximization can be the key to achieving a high-performance self-compacting concrete type. Moreover, the quality of the "transition zone" as the weakest connection point in the concrete would be improved due to the reduction in the porosity. It has been understood from the results of the prior research that the failure surface does not extend to the transition zone in highly resistant concrete, which features a relatively large density. Rather it is stretched to the aggregate particles (Seyed Fathollah Sajedi and Milad Orak, 2020). Many Researchers have included crumb rubber as concrete aggregate in their research. Some of them also have come up with improvements in compressive strength (Adesina and Atoyebi 2020, Fellipe Rodrigues André, Mostafa Galal Aboelkheir 2022, Nurul Izzati Rahim et al. 2022, Hashem Jahangir et al. 2022, Rahul Kumar and Nirendra Dev 2021). Despite of many researchers tried to use waste tiers as aggregate in concrete, many researchers considered using crumb rubber in self compacting concrete (SCC) (Okorie et al. 2022, Sylvia(a) et al. 2022, Yarivan and Khaleel 2022, Sylvia(b) et al. 2022). While many studies have been carried out using crumb rubber, many research showed that using waste tiers decreases the compressive strength of concrete. Therefore, in this paper using crumb rubber with microsilica gel were used in SCC. Microsilica gel is usually used to increase compressive strength of concrete.

2. Study Method:

This research used crumb rubber, made from small pieces of discarded tires from heavy and light vehicles, as a replacement for sand in concrete. The crumb rubber pieces were between 1 to 3 millimeters in size. The cement used was Type II from Firoozabad in Fars Province, Iran, and the aggregates were obtained from the Moradi Mine. The water used was drinkable water from Shiraz, and all filler additives were sourced from industrial villages in Shiraz. The AI-544 standard was followed in this study.
The aggregation plan was established with a water to cement ratio of 0.5 and amounts of sand, gravel, and cement based on granulation. The crumb rubber was replaced with sand and gravel by weight percentage to facilitate the process. Three weight percentages of 5, 7.5, and 10 were used for sand substitution, based on the best weight percentage reported in previous research. It is important to note that the construction materials, cement structure, and chemical properties may vary in different regions and weather conditions. After tests and preparation of the moulds, the specimens were made according to the aggregation plans. The concrete was poured into the moulds and allowed to set for 24 hours in a

cool, shaded location. The specimens were then transferred to water ponds. Table 1 shows the weight ratios of the primary concrete materials and the water-to-cement ratio.

Table 1:The final aggregation scenario

Water to cement ratio	Cement	Water	Fine grains	Coarse grains
0.5	450	225	1090	650

The W/C ratio was chosen based on previous research and the MCI2/1 standards, while also considering the average water-to-cement ratio in Shiraz, which is between 0.4 and 0.51. After initial setting inspection, the concrete samples were removed from the molds after 24 hours and kept in water ponds under standard conditions for 28 days. Table 2 presents the specifications, weight percentages, and coded names of the samples used in this study.

Table 2:Specifications of the specimens

Specimen type	W/C	Weight of the used materials		Microsilica gel	Explanations
		Cement	Rubber		
C450T0	0.5	450	0.0	0	Control specimen with no additives
C450T5	0.5	450	32.5	Cement for 2% of weight percentage	Replacing sand with crumb rubber for 5% of the weight
C450T7.5	0.5	450	48.75	Cement for 2% of weight percentage	Replacing sand with crumb rubber for 7.5% of the weight
C450T10	0.5	450	0.65	Cement for 2% of weight percentage	Replacing sand with crumb rubber for 10% of the weight

The aggregates were made by weighing the necessary construction materials, mixing the dry sand and gravel in the concrete lab's mixer for 30 seconds to achieve a homogenous mixture, and then adding the previously weighed cement and stirring for an additional 30 seconds. Next, 65% of the water was added to the dry mixture and mixed for two minutes, followed by the addition of 33% of the remaining water and mixing for five minutes, during which time micro-silica gel was also added. After the construction process was complete, a slump test was immediately conducted on the fresh concrete mixture. Sampling was then started following the tests on the fresh concrete. The hardened concrete samples were in the form of 15x15x15 cubic specimens, which were prepared and coded for compressive strength testing.

In this research, 15x15x15 cubic specimens were constructed and tested in a moist environment after curing. Loading was applied continuously at a shock rate of 0.2-64 to record the maximum load, and the compressive strength was determined by dividing the maximum load by the sample's cross-section and rounding to the nearest number. It is important to note that the sample's failure should be optimal to ensure the accuracy of the test, and this is indicated by a shape that consists of two imperfect conic lines connected at the top.

3. Results and discussions:

The results of the compressive strength of concrete for various days are shown in Figure 1. Figure (a) indicates that the inclusion of microsilica gel increases the compressive strength of concrete compared to plain concrete. On the other hand, the addition of crumb rubber particles is expected to reduce the compressive strength of concrete, as seen from C450T5 to C450T10. This reduction is approximately 10% for 28-day samples. Similar trends can be seen in the results for 7, 28, 90, and 120 days in figures (b), (c), and (d). It is notable that the trend of reduction in the 28th, 90th, and 120th days is faster, suggesting that the increase of crumb rubber particles in concrete with longer curing leads to a greater decrease.

The results show that the trends of compressive strength increase for concrete containing crumb rubber differ in the early stages (first seven days) from the older stages (from 7 to 90 days). This difference is likely due to the ascending speed of hydration for concrete from zero to 28 days and the descending speed of hydration for concrete from 28 to 90 days. It is also important to consider the preservation conditions of the concrete during this period. In addition, the compressive strength of the concrete is closely related to the size and mixing ratio of the crumb rubber, the type of mixing, sand and gravel washing, and the setting time. As mentioned for the 28-day-old samples, the growth rate slows with increasing age compared to self-compacting concrete specimens containing crumb rubber, which show a more significant growth. In other words, more concrete durability experiments using crumb rubber should be conducted. However, it appears that mixing with crumb rubber does not produce good results in the long term, even though good results were obtained in terms of aggregation and concrete homogeneity after 28 days and a slow growth in compressive strength was observed.

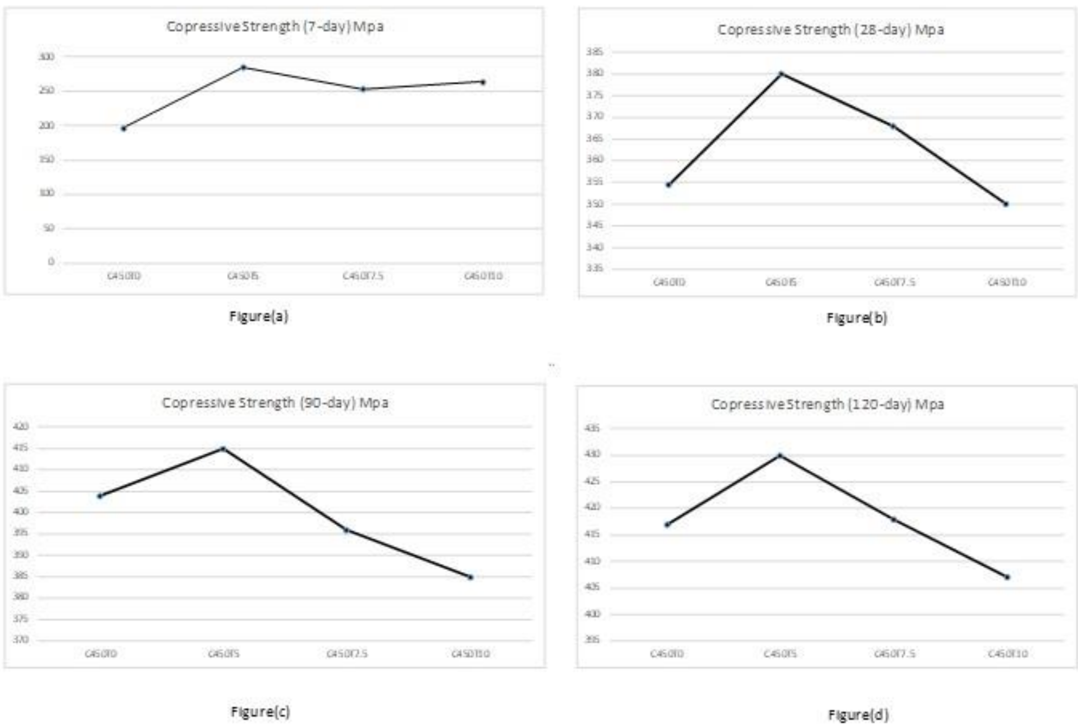

Figure 2 Compressive Strength of Concrete

Table 3 and Figure 2 have been presented to compare the results of different ages. All samples with different ratios of crumb rubber have a similar trend in the compressive strength of concrete. As expected, a higher ratio of crumb rubber leads to lower compressive strength of concrete. It is also worth noting that the sample without crumb rubber (C450T0) has a steeper slope, indicating that crumb rubber may potentially impact the long-term behavior of concrete. Further study is needed to confirm this.

The increase in the amount of rubber causes a reduction in the compressive strength of the concrete because the compressive strength of the sample containing rubber was higher than that of the control specimen at lower mixing ratios. In other words, an increase in the percentage of rubber in the concrete causes a downward trend in compressive strength. This is while the compressive strength has increased for 5% substitution rates (gravel). The results show that there is a five percent decrease in compressive strength for the 90-day-old concrete specimen. The highest increase is seen in the scenario where crumb rubber is added at a 5% rate, with a 45% increase in compressive strength compared to the control specimen at 7 days. There is also a 3% increase in compressive strength, i.e., 415kg/cm2, for the 90-day-old concrete specimen.

Table 3: Compressive Strength of Concrete

No.	Name	Compressive Strength (7-day) Mpa	Compressive Strength (28-day) Mpa	Compressive Strength (90-day) Mpa	Compressive Strength (120-day) Mpa
1	C450T0	197	354.5	404	417
2	C450T5	285	380	415	430
3	C450T7.5	253	368	396	418
4	C450T10	264	350	385	407

For the 7-day-old concrete, there is a 45% increase in compressive strength compared to the control concrete, with the highest initial growth in compressive strength from 197kg/cm2 to 285kg/cm2. There is also a 3% increase, i.e., 415kg/cm2, for the 90-day-old concrete specimen. The most significant reduction occurs when crumb rubber is added at a 10% rate, resulting in a 5% reduction in compressive strength to 385kg/cm2 for the 90-day-old concrete. These results were obtained for a standard rate of replacing crumb rubber, 1-3mm in size, at 5% for fine-grained sand. The use of microsilica gel-containing cement at 2% has also significantly improved compressive strength.

4. Conclusions

Over the past 20 years, the use of various types of urban waste in the construction materials industry has been a major focus. It is important to consider using industrial materials in concrete without significantly decreasing its compressive strength. This study showed that it is possible to use waste tires as coarse aggregate in concrete without decreasing its compressive strength. One way to increase the compressive strength of concrete containing crumb rubber is to use additive materials such as microsilica gel, which was used in this study. To fully understand the behavior of concrete containing waste materials, other tests such as tensile strength of concrete could also be conducted. The authors believe that adding crumb rubber could lead to better energy dissipation in a structure under dynamic loading.

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