Rheological and Mechanical properties of self-compacting ground rubber modified concrete

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Abstract: A test program was carried out to develop information about the rheological and mechanical properties of rubberized self compacting concretes (RSCC) with and without silica fume. In the present work, two types of aggregates dolomite and gravel with nominal maximum size 20 mm were used in concrete mixes at constant cement content for all mixes equal to 350 Kg/m^3. Silica fume and ground waste tire rubber (GWTR) were added to concrete mixes by about 10% of weight of cement. Also viscosity-enhanced admixture (VEA) was introduced in all mixes with three different levels 1.0, 1.5 and 2% by weight of cement content. The properties of fresh concrete were measured by means of slump flow v-funnel and l-box tests. The behavior of hardened concrete was investigated in terms of compressive and tensile strength up to 28 days. Test results showed that using the ground rubber tire enhance the rheological properties of self-compacting concrete for all mixes. Addition of ground powder of waste rubber to concrete mixes resulted in reduction in the compressive strength by about 22% compared with conventional concrete mixes. Also test results indicated that there was a partial reduction in compressive strength values with the increase in rubber content. However, the addition of silica fume into the matrix improved the mechanical properties of the rubberized concretes and diminished the rate of strength loss.

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1. Introduction

Solid waste management is one of the major environmental concerns in all over the world. High amounts of waste tires are generated each year and utilization of this waste is a big problem from the aspects of disposal, environmental pollution, and health hazards. In the production of self-compacting concrete, the incorporation of waste tires as partial replacement of aggregates is very limited. However, the use of waste tires might join the characteristics of self-compacting concrete (high flowability, high mechanical strength, low porosity, etc.) with the tough behavior of the rubber phase, thus leading to be a building material with more versatile performances.

Based on the properties measured, rubberized concrete is suitable for: architectural applications (e.g. nailing concrete, false facades, stone backing, and interior construction because of its light unit weight), low-strength-concrete applications (e.g. sidewalks, driveways and selected road construction applications), and crash barriers around bridges (high plastic energy absorption). It is speculated that the material can be used in sound barriers and vibration control applications because of its apparent high sound attenuation and vibration absorbency [1].

However, regardless the different nature, size and composition of used tire rubbers, a meaningful decrease in concrete compressive strength with the increasing amount of rubber phase in the mixture were always detected. Although the so far obtained rubberized concrete generally shows a tougher behavior with a gradual failure of the samples than traditional concrete, it generally does not exhibit suitable compressive strength for structural applications [2]. On the other hand, concrete has undergone several changes in its formulation and technology to become stronger and durable: with this purpose fly ashes [3,4], fly ashes and polymers [5–7], silica fume [8,9], superplasticizer, etc. have been added to the traditional mix and recently self-compacting characteristics have been achieved for tailored preparations [10]. Self-compacting concrete (SCC), although developed with the aim to make easier compaction, is a new type of concrete that attains higher compressive strength and durability in comparison with ordinary Portland cement concrete (OPCC), thanks to the addition of fine filler and proper admixtures, i.e. superplasticizers and modifying viscosity agents [11–13]. The combination of these components leads to a mixture that does not require vibrations on placing, with time and cost saving of building site procedures. However, in spite of the fine filler presence (usually with an average size about 10–30 μm) promoting the formation of very compact microstructure and allowing high values for compressive strength, the failure behavior in SCC is still brittle.

The United States used the tires as asphalt mixtures for highways as an alternative to landfill disposal; however, there were many technical problems and resistance from industry groups. The workability, mechanical properties, and chemical stability of a recycled tire rubber-filled cementitious composite were evaluated [14]. As expected, the geometry of the rubber particles influenced the fracture behavior of rubber-containing mortar. The addition of rubber led to a decrease in flexural strength and plastic shrinkage cracking of mortar. The rubber shreds bridged the cracks and provided restraint to crack widening [14,15]. Due to its low specific gravity, crumb rubber can be considered a lightweight aggregate.

Self-compacting concrete that is able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without the need of any vibration, whilst maintaining homogeneity. Self-compacting concrete (SCC), although developed with the aim to make easier compaction, is a new type of concrete that attains higher compressive strength and durability in comparison with ordinary Portland cement concrete (OPCC), thanks to the addition of fine filler and proper admixtures, i.e. superplasticizers and modifying viscosity agents [16–18]. The combination of these components leads to a mixture that does not require vibrations on placing, with time and cost saving of building site procedures. The possibility to design self-compacting rubberized concrete (SCRC) appears particularly attractive because this new material might join the characteristics of SCC (high flowability, high mechanical strength, low porosity, etc.) with the tough behavior of the rubber phase, thus leading to a building material with more versatile performances. Previous studies [19,20] have been carried out to verify the feasibility of SCRC: self-compacting rubberized mortars were prepared to evaluate the optimum amount of tire rubber that could be introduced in the mix avoiding severe loss of compressive strength and still maintaining the self-compacting characteristics.

Self-compacting concrete is a product of technological advancement in the area of under-water concrete technology where the mixture is proportioned to ensure high fluidity while providing high resistance to water dilution and segregation. The use of SCC has gained wide acceptance in Japan since the late 1980's for casting congested members as well as well as the placement of concrete in restricted areas where consolidation may not be practical [21-24]. In general, SCC is used to facilitate the filling of congested structural sections and cast elements with restricted access for placement and consolidation. Superplasticizers are an essential component of SCC to provide the necessary workability. Other types may be incorporated as necessary, such as Viscosity Modifying Agents (VMA) for stability, air entraining admixtures (AEA) to improve freeze-thaw resistance, retarders for control of setting, etc. Self-compacting concreting concrete can also be used in casting non-congested structures where limitation of concrete consolidation or the required duration of intervention can reduce construction costs as well as noise, which can be important in some urban areas. This can contribute to an improvement in working conditions and overall productivity of the construction site. Because of the highly stable nature of SCC, its use can enable the casting of deep sections in fewer lifts without greater risk of settlement, segregation, or bleeding. This can reduce the number of lifts in deep sections, hence decreasing construction time and labor requirements.

The main goal of this study is to investigate the effect of using recycled powder waste rubber tires as an addition of cement content on the properties of self compacting concrete (SCC) containing 10% silica fume for different types of aggregates. The cement content for concrete mixes was 350 Kg/m^3. Two types of aggregates, gravel and dolomite with size 20 mm were used. The effect of a Viscosity Enhanced Admixture (VEA) added to concrete mixes with three different dosages: 1, 1.5 and 2% of cement content was also under investigation.

2. Experimental Work

Type of powder, Type of aggregate, and dosage of a Viscosity Enhanced Admixture (VEA) were the main variables taken into consideration in this work. All variables were reported in Table 1.

Materials

The waste rubber used in this research is getting it from the truck tire rubber which mill by different sizes < 0.125 mm after the exclusion of the part containing steel and textile fibers in their composition. The ground process was obtained mechanically by using Al-Nasser Company for rubber product. The specific gravity and unite weight of the used fine ground waste tires rubber (GWTR) are 0.9 and 0.67 g/cm^3 respectively. The measured values of chemical compositions of ground waste tires rubber are 82% carbon, 1.3% sulfur, 6% ash and 8% hydrogen. Silica fume is a fine powder, which acts as pozzolanic material containing more than 90% silicon dioxide, its specific surface area 20,000 cm^2/gm. Silica fume and fine powder waste tire rubber were added to concrete mixes as an addition by the ratio of 10% of cement content. A locally produced, type I ordinary Portland cement was used. The cement content was added at constant level equal to 350 kg/m^3. Mixing water was clean tap water free from impurities and organic matters, added at constant level equal to 180 lit/m^3 for all mixes. Siliceous sand with 100% passing ASTM sieve No. 4 and the fineness modulus of 2.75 was used. Two types of aggregates, gravel and dolomite with size 20 mm were used. The specific gravity of the coarse aggregate and sand were about 2.6 and 2.5 respectively. The coarse aggregate were washed carefully and dried before mixing to remove any impurities and organic matters. The weight of sand and coarse aggregate in all mixes was 800 and, 900 Kg/m^3 respectively. A Viscosity enhanced admixture (VEA) is introduced in all mixes with three different dosages: 1, 1.5 and 2% of cement content.

Specimen preparation:

Cubes 150 mm × 150 mm × 150 mm and Cylinders 150 mm diameter and 300 mm height were used for casting the concrete compression and indirect tension test specimens respectively. The ground waste tires rubber (GWTR) particles and/or silica fume were added to the cement content and mixed well with it before mixing the concrete components. Dry materials were mixed first in the dry state to insure the homogeneity of the mixture, and then 2/3 of the gauging water is added gradually during the mixer rotation. The admixture (VEA) is then added to the remaining water (1/3 of the gauging water) and introduced gradually over 30 sec., and the concrete is mixed for another 120 sec. To determine the flowability and viscosity of each mix the slump flow, V-funnel, L-box and segregation tests are used as shown in Fig. (1). The slump flow is measured immediately after mixing; afterwards the V-funnel efflux time is determined followed by the L-box test.

Three test specimens were prepared for each mix without any internal or external compaction and removed from moulds after 24 hours from casting. Submerging in tap water for 28 days at room ambient temperature cured the compression and tensile test specimens. A compression-testing machine of 3000 KN maximum capacities was used for the completion of both the compression and indirect tension test for concrete. In each test the crushing load was recorded for the estimation of the compressive and indirect tensile strength.

Table 1. Experimental Program.

Mix Code	Type of Aggregate	Type of powder			Viscosity Enhanced Admixture (VEA) %	Cement Content kg\m³	Water Content lit/m³
		Silica fume	Rubber	Silica fume + Rubber			
NG1	Gravel				1%	350	180
NG2					1.5%		
NG3					2%		
ND1	Dolomite				1%		
ND2					1.5%		
ND3					2%		
G1	Gravel	10%			1%	350	180
G2			10%				
G3				5% + 5%			
D1	Dolomite	10%					
D2			10%				
D3				5% + 5%			
G4	Gravel	10%			1.5%	350	180
G5			10%				
G6				5% + 5%			
D1	Dolomite	10%					
D2			10%				
D3				5% + 5%			
G7	Gravel	10%			2%	350	180
G8			10%				
G9				5% + 5%			
D1	Dolomite	10%					
D2			10%				
D3				5% + 5%			

3. Results and Discussion

1. Properties of Fresh Concrete

In terms of slump flow diameter, slump flow time (T_{50}), V-funnel flow time (efflux time) and H\L ratio of L-box test, the properties of fresh concrete were measured and plotted in Figs 3 to 10. In general from these figures it can be noticed that, the slump flow diameter increases for all type of used powder as a function of the dosage of viscosity enhanced admixture (VEA). The higher values of slump flow diameter was obtained when using silica fume as powder in concrete (SF.C) followed by the results obtained from the mixes containing mixture from the silica fume and rubber (SF.RC) and finally the mixes containing rubber powder (RC) only gives less value f slump flow but still higher than that obtained from normal concrete (NC). All mixes containing gravel give higher values of slump flow diameter rather than the mixes containing dolomite as coarse aggregate by about 10% as shown in Fig 3 and 4. These results may be due to the smooth surface gravel compared to the dolomite as coarse aggregate. For example, it is clear when using silica fume as powder in concrete (SF.C) have higher effect on the flowability of concrete, the slump flow diameter of the mix containing silica fume as powder was 735 mm and reached to 690 mm when using mixture from the silica fume and rubber (SF.RC) but reached to 655 when using rubber powder (RC) only. These values were obtained when VEA equal to 2% for gravel concrete.

The time required for the concrete mixes to reach a 500 mm slump flow diameter (T_{50}) was illustrated in fig 5 and 6 for gravel and dolomite concrete respectively. As shown in these figures it was clear that the RC, SF.RC, and SF.C mixes consumed low time to reach a 500 mm slump flow diameter compared to that of normal concrete. Using silica fume as powder rather than mixture from the silica fume and rubber, or rubber powder only decreased this time. For all mixes slump flow time (T_{50}) is decreased with increasing the dosage of VEA. For example, these reductions in (T_{50}) were 23%, 40% and 60% for RC, SF.RC, and SF.C mixes respectively compared with NC mix for dolomite concrete at dosage of VEA equal to 2%. A pronounced observation in the slump flow test for all mixes is that there is no horizontal segregation of coarse aggregates near the edges of the spread out concrete. This observation reflecting the enhanced viscosity and stability of all mixes regardless of the existence of fine powder and admixture contents. The enhancement of concrete flowability may be due to that the fine powder (silica fume, mixture from the silica fume and rubber, rubber powder) as will as fillers that are combined to enhance the grain size distribution, packing density, and reduce inter-particle friction and consequently leads to attain a given viscosity. Finally it can be conclude that using waste tire rubber give little effect on the concrete flowability. This effect can be increased by mixed silica fume with rubber powder, while silica fume give the best result of concrete flowability.

The results obtained from V-funnel test for different type of aggregate were plotted in Figs. 7 and 8. In general the gravel concrete mixes give lower values of efflux time compared with dolomite concrete. Also, the increase of the dosage of VEA resulted in a decrease in efflux time for all concrete mixes. Short efflux time was recorded for all mixes containing powder compared with that recorded for normal concrete. SF.C mixes give the lower values of efflux time than SF.RC mixes or RC concrete mixes.

L-box test results are plotted in Figs. 9 and 10 for gravel and dolomite concrete respectively. These figures indicated that, the maximum spread distance (L_{max}) of concrete in significantly higher values of gravel concrete than dolomite concrete, while the average surface gradient (H\L ratios) were lower values of gravel concrete compared with dolomite concrete. For all types of powder used in various concrete mixes, H\L ratios were decreased compared with normal concrete. Better results were obtained by using silica fume as powder rather than mixture from the silica fume and rubber or rubber powder only. This behavior indicates that providing adequate viscosity during deformation of the concrete reduces the risk of blockage. This may reduce inter-particles friction, which limits deformability in narrow spaces and reduce the filling ability of concrete.

2. Properties of Hard Concrete

The mechanical properties of SCC containing gravel or dolomite as coarse aggregate were investigated in terms of compressive strength and tensile strength.

2.1Compressive strength:

The test results were illustrated in Figs.11s&12. Similar behavior was observed for compressive and tensile strength where dolomite concrete gives high values of compressive and tensile strength than gravel concrete. About 22% reduction in compressive and tensile strength was recorded for test specimen containing rubber waste tire as powder in concrete. These reductions in compressive and tensile strength reduced by about 10% when using mix of silica fume and rubber in concrete mix. The reduction in compressive can logically be attributed to (i) the low modulus of elasticity (E) for rubber particles and high Poisson ratio (v) which may encourage premature cracking under load, (ii) increased porosity due to air entrainment from rubber particles [16,18–20], and (iii) weak bonding in the interfacial transition zone between the cement paste and rubber particles which could be due to crack initiation from the voids that form between crumb rubber particles and cement paste, as observed by Aiello and Leuzzi [23]. Therefore, under compression loading the aggregates can be susceptible to pullout resulting in particle perimeter voids and crack initiation sites.

These figures show that, the strengths were improved by increasing the dosage of VEA from 1 to

2%, compared with normal concrete (NC). This improvement in strength may be due to that VEA can ensure high deformability and adequate stability leading to greater filling capacity, destroy the formation of internal pores and better homogeneity of hardened properties. The compressive and splitting failures of concrete specimens containing waste tire rubber show large compressibility of the material and did not exhibit the typical brittle failure normally associated with the normal concrete.

2.2 Tensile strength

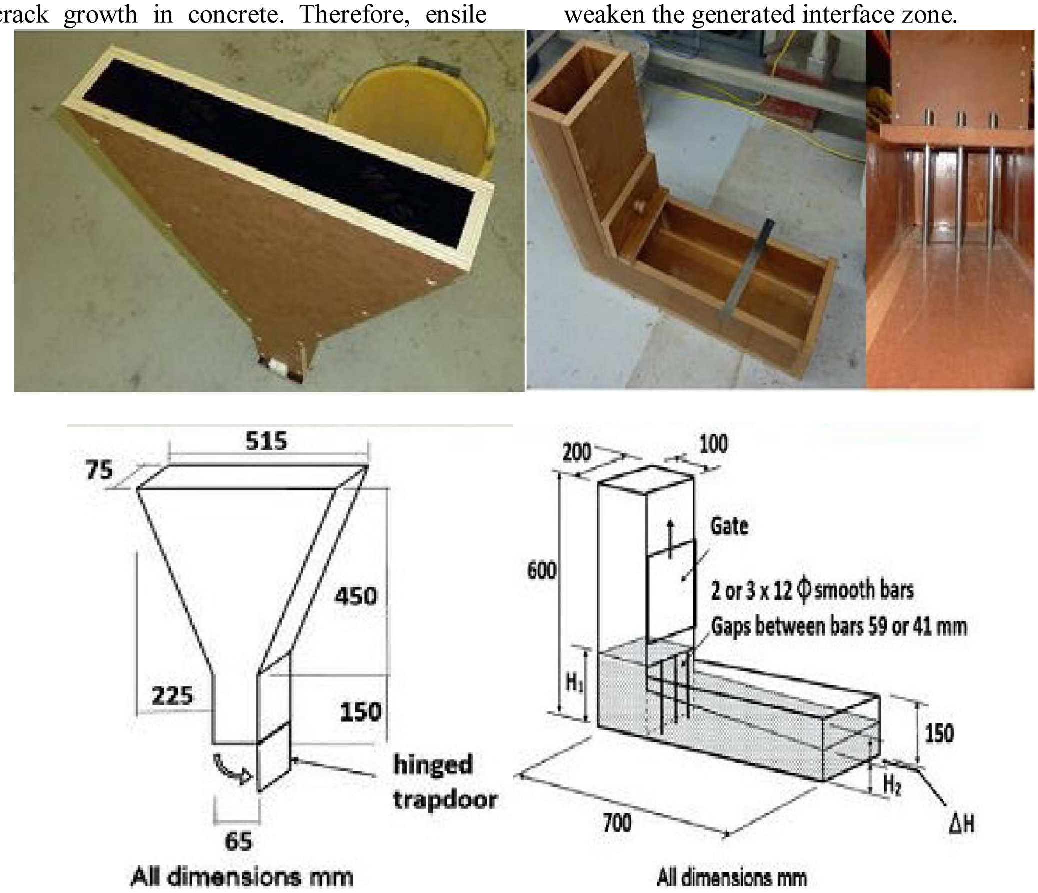
The results of tensile strength test are given in Figs.13&14. Tensile strength of concrete was reduced with replacement of rubber in both mixtures. The percent reduction of tensile strength in the first mixture was about twice that of the second mixture for lower percentage of replacements. The reduction in tensile strength with 10% replacement was 17% compared to the control mixture. These reductions in tensile strength was also reduced by about 10% when using mix of silica fume and rubber in concrete mix.

Tyre rubber as a soft material can act as a barrier against crack growth in concrete. Therefore, ensile strength in concrete containing rubber should be higher than the control mixture. However, the results showed the opposite of this hypothesis. The reason for this behavior may be due to the following variables:[25]

1- The interface zone between rubber and cement may act as a micro-crack due to weak bonding between the two materials; the weak interface zone accelerates concrete breakdown.

2- Inspections of the broken concrete samples proved that the rubbers were observed after breaking the concrete specimens in the first mixture. The reason for this behavior is that during crack expansion and when it comes into contact with rubber particle, the exerted stress causes a surface segregation between rubber and the cement paste. Therefore, it can be said that rubber acts just as a cavity and a concentration point leading to quick concrete breakdown.

3- Another variable which may affect concrete behavior is actually the main region of segregation when tensile strength is exerted on the boundaries of the large grains and cement paste which in turn weaken the generated interface zone.



V-funnel L-Box

Fig. 1. V-funnel and L-box.

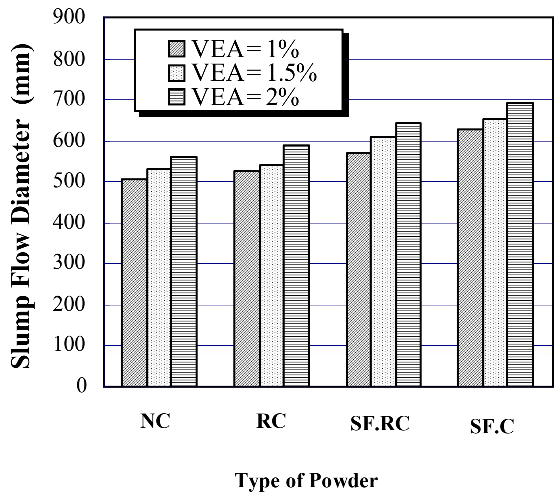


Fig. 3. Slump Flow Diameter of Different Mixes Containing Dolomite Aggregate.

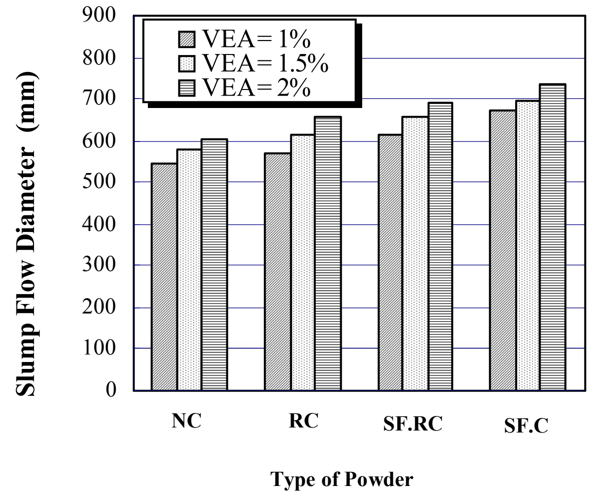


Fig. 4. Slump Flow Diameter of Different Mixes Containing Gravel Aggregate.

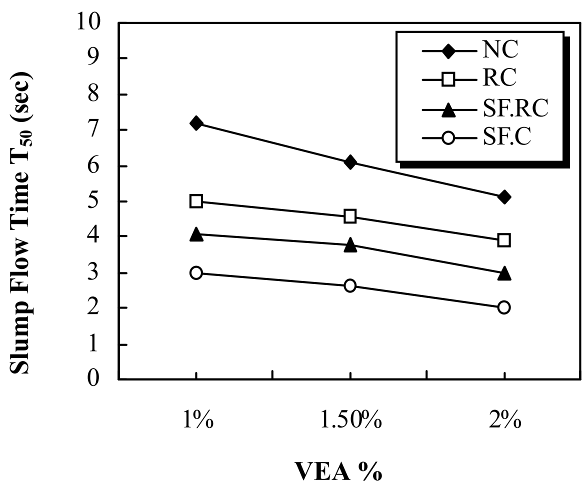


Fig. 5. Slump Flow Time (T_{50}) of Different Mixes Containing Dolomite Aggregate.

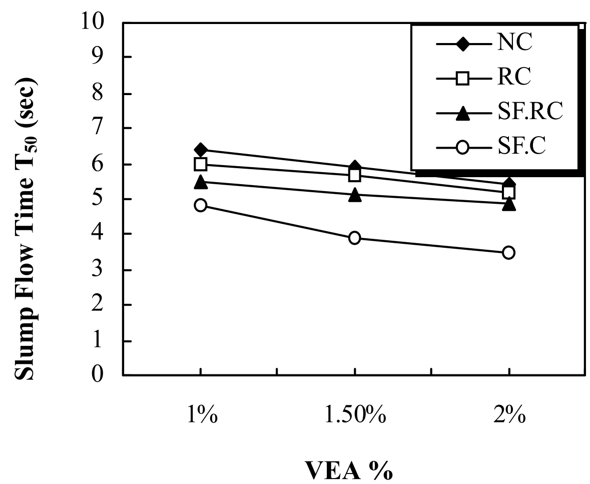


Fig. 6. Slump Flow Time (T_{50}) of Different Mixes Containing Gravel Aggregate.

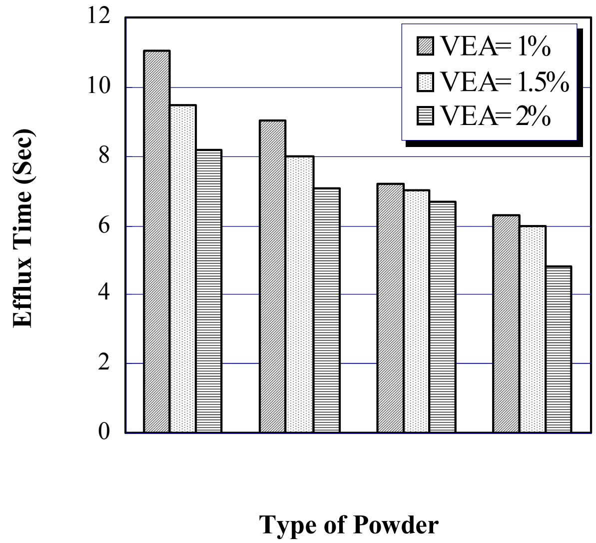


Fig. 7. V-Funnel Flow Time of Different Mixes Containing Dolomite Aggregate.

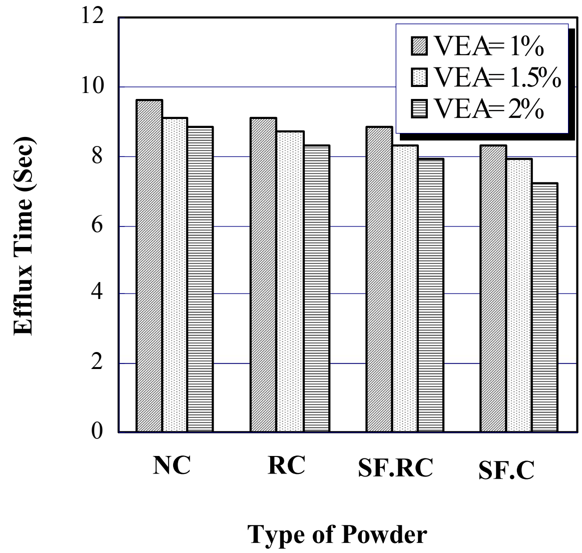


Fig. 8. V-Funnel Flow Time of Different Mixes Containing Gravel Aggregate.

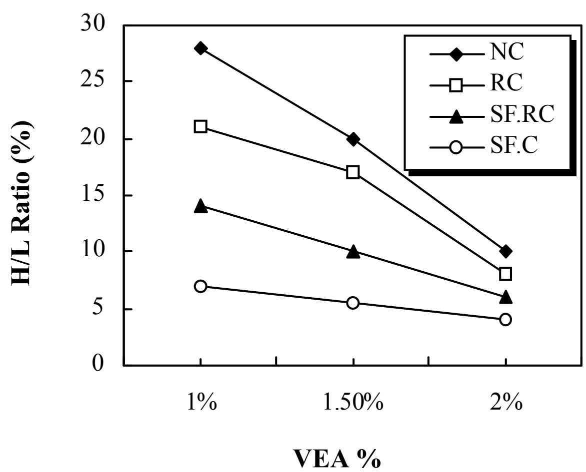


Fig. 9. H/L Ratio of Different Mixes Containing Dolomite Aggregate.

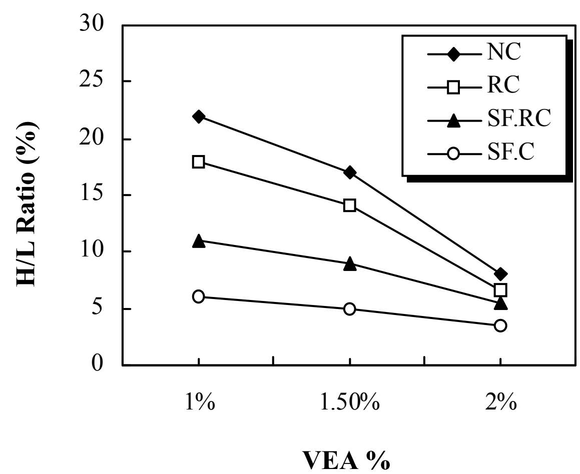


Fig. 10. H/L Ratio of Different Mixes Containing Gravel Aggregate.

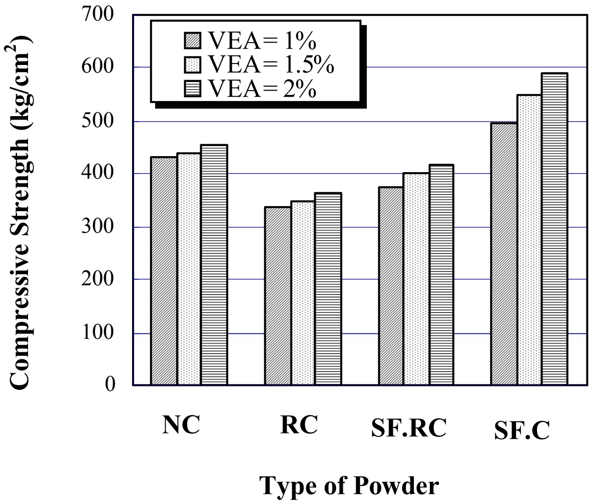


Fig. 11. Compressive Strength of Different Mixes Containing Dolomite Aggregate.

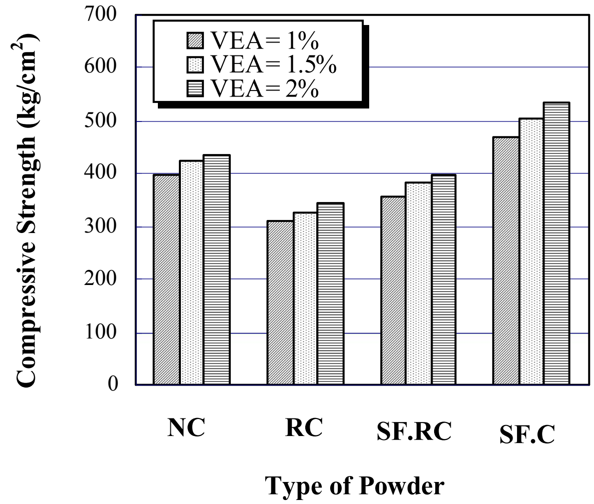


Fig. 12. Compressive Strength of Different Mixes Containing Gravel Aggregate.

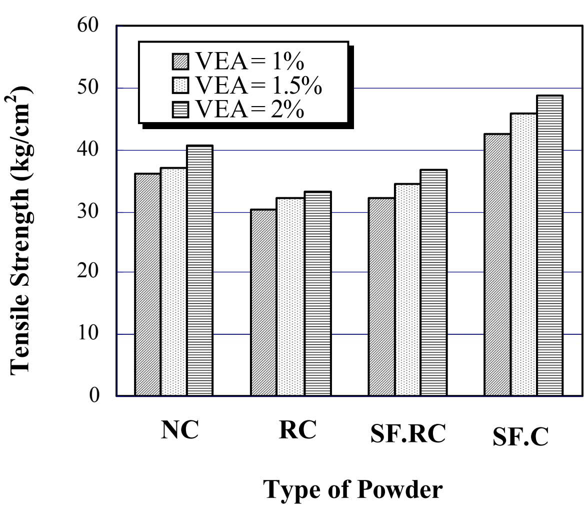


Fig. 13. Tensile Strength of Different Mixes Containing Dolomite Aggregate.

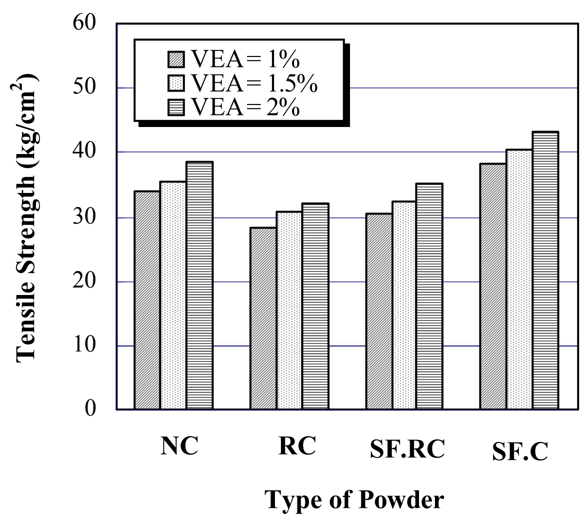


Fig. 14. Tensile Strength of Different Mixes Containing Gravel Aggregate.

Conclusions

Self Compacting Rubberized Concrete (SCRC) has mechanical properties sufficient for structural applications (f_c > 30MPa). Addition of ground waste tires rubber as a fine powder by weight of cement content resulted in a slight increase in the concrete flowability compared with normal concrete. Rheological properties enhanced for all types of used powder as a function of the dosage of viscosity enhanced admixture (VEA) up to 2%.

The mechanical properties of concrete containing dolomite higher than that containing gravel, unlike decrease in rheological properties of fresh concrete containing dolomite as compared by that containing gravel. The reduction in compressive and tensile strengths of concrete containing ground waste tire rubber can be limited by using silica fume as addition mixed with waste tire rubber. Tensile strength of concrete was reduced with 10% of ground rubber addition in concrete by about 17%. The most important reason being lack of proper bonding between rubber and the paste matrix, as bonding plays the key role in reducing tensile strength**.** These reductions in compressive and tensile strength reduced by about 10% when using mix of silica fume and rubber in concrete mix.

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