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Positive and Negative Influences of Waste Tires on Self-compacting Concrete: A Summarized Review

Mehdi Jafari[1*], Amir Mohammad Mozhdehi[2], Ahmad Ganjali [3]

1-Department of Civil engineering, Shahrood Branch, Islamic Azad University, Iran
2-Department of Civil engineering, Shahrood Branch, Islamic Azad University, Iran
3-Department of Civil engineering, Shahrood Branch, Islamic Azad University, Iran

*mehdijafari.ce@gmail.com

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Abstract

In recent decades, manufacturing of tires have been rocketed. The main cause of this process is development of automobile industry in worldwide, so the high volume of scrap tires has been created massive stockpiles zones. Furthermore, environmental threat related to waste tires, and disposing them properly has come to a world crisis, due to the requirement more spacious storage than other wastes and the massive volume and their fixed shape. Therefore, there is immediate and effective need of recovering and reusing waste tires.

Waste tires have efficient applications in engineering, especially mortars and concrete. The results of various investigations have demonstrated that rubberized self-compacting concretes show lower compressive strength, modulus of elasticity, stiffness, rheological properties, fracture energy, durability, flexural strength, ultrasonic pulse velocity etc. and higher deformability before failure, saving in cement and aggregate usage, dynamic properties, strain capacity, fatigue strength etc. Therefore, adding waste rubber into self-compacting concretes leaves a numerous positive and negative impacts on its properties.

In this paper, authors present an overview of literature investigating of waste rubber used as an additive or fine and/or coarse aggregate replacement in self-compacting concrete with special attention on positive and negative influences on fresh and hardened self-compacting concrete properties.

Keywords: Self-compacting concrete; Waste tire; Rubberized self-compacting concrete; Waste rubber; Self-compacting concrete properties

1- Introduction

Since the self-compacting concrete (SCC) has been developed, engineers have applied it as a creative and practical approach in building industry due to its exclusive properties like ability of flowing under its own weight. SCC also was used with the aim of tackling some problems like honeycombing and giving better finishes to structures. It is good alternative of conventional concrete especially where congestion of reinforcement occurs [1-2].

Another merit of SCC could be the reduced required time to place large sections. SCC also provides benefits beyond those of conventional concrete in all three aspects of sustainable development: economic, social and environmental.

Replacing a part of mineral aggregates in SCC with industrial wastes such as rice husk ash, marble dust, recycled aggregates, silica dust, scrap rubber, glass aggregates, and fly ash could be considered as a way to increase the sustainability of SCC to make sustainable concrete [1,3–7].

The rubberized concrete is found to be a perfect material for the structural members exposed the rapid effects and for which preferred toughness or deformation ability holds greater significance than strength, like road foundations, jersey barriers and bridge barriers.

Rubberized concrete has beneficial attributes to reduce the vibration and to absorb the impact energy more efficient than the conventional concrete. It also able to decrease the use of conventional materials in the concrete matrix along with recycling of waste rubber tires [1,3,4,6].

Until recently, many review papers on SCC and reinforced-SCC with industrial wastes have been written by many researchers [8–11], and have shown that the performance of SCC can be significantly increased by using them. The objective of the present review is to provide a literature review on various methods which have been developed over a recent period of time in field of using of waste tires in SCC.

2- Literature review

M.C. Bignozzi and co-workers [12] prepared rubberized self-compacting concrete(SCC) containing different amounts of untreated tire waste and their mechanical and microstructural behavior were investigated.

In their investigation they selected three concrete mixes including SCC-A, SCC-B, and SCC-C.

SCC-A mix is a formulation for self-compacting concrete, with water /cement and water /powder mass ratios of 0.53 and 0.34, respectively, adjusted in previous works[13,14]. The same W/C and W/P mass ratios were used in SCC-B and SCC-C where respectively 22.2 and 33.3 v/v% of sand were replaced by tire rubber wastes.

Load–displacement curves were recorded under compressive test for the mixes SCC-B and SCC-C at a constant strain rate of 15 mm/min: the relevant stress–strain plots are reported in fig1. The decrease in strength and stiffness is strictly connected with the presence of the rubber phase: under compressive load, tire rubber particles deboned from cement paste causing voids that unavoidably make failure easier [15].

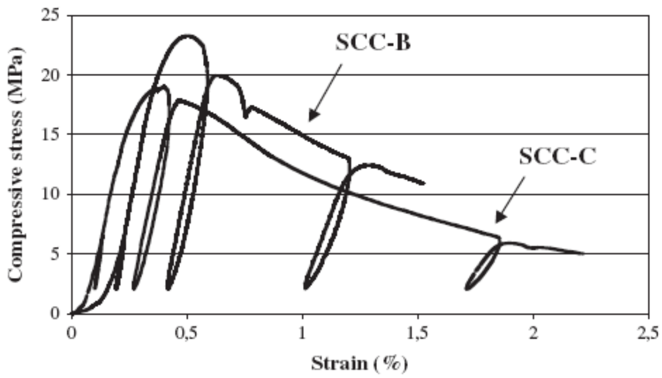


Fig1- Stress–strain curves for SCC-B and SCC-C [12]

With the aim to verify if the self-compacting technology is more fruitful in preparing rubberised concrete than traditional one, a comparison of the results of present study with those of previous investigations were reported (Fig. 2).

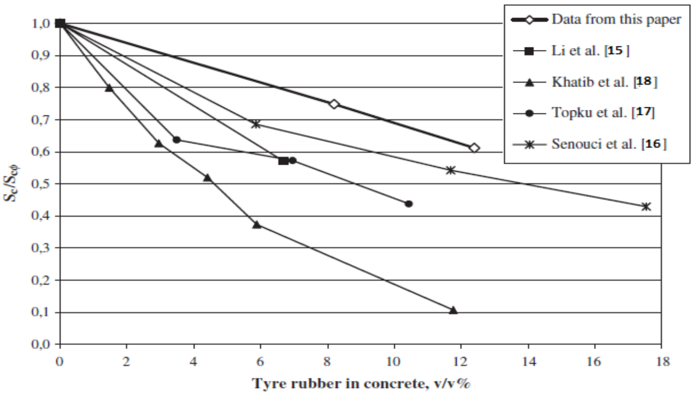


Fig2- Compressive relative strength as function of tire rubber volume in concrete [12]

They published their results as below:

- SCRC (self-compacting rubberized concrete) requires slightly higher amount of superplasticizer than SCC to reach self-compacting properties, keeping constant water/cement and water/powder weight ratios.

- Concrete compressive strength and stiffness decrease with increasing amount of rubber phase in the mix, but the obtained values are higher than those of ordinary Portland cement concretes admixed with similar amounts of tire rubber wastes.

- Significant concrete deformability before failure and capability to withstand post-failure loads with some further deformations are exhibited by SCRC due to the tire rubber waste presence.

- SCRC porosity is only poorly affected by the presence of significant amount of rubber phase in comparison with that of ordinary SCC.

In another study, İlker BekirTopçu et al [16] did an experimental investigation on some fresh and hardened properties of rubberized self-compacting concrete (RSCC). They reported a new usage method for RA in SCC formulation. They claimed that RA content which was used about 180 kg/ m^3 has beneficial effects on both fresh and hardened properties of SCC compared to ordinary concretes. Thus, RA can be recycled at higher amounts, the environmental pollution can be prevented and economic advantages can be provided. Interestingly, the conclusions of their study were in accordance with the conclusions of a previous study by Bignozzi and Sandrolini [12].

For one control SCC mixture and three RSCC mixtures they found that when the properties of fresh SCC such as slump–flow, T50 and V-funnel times are considered as a criterion to determine the optimum usage ratio of RA in SCC, it can be said that usage amount up to 180 kg/m3 content is suitable for improving all of these properties especially related to the properties of the agent used when it is used in SCC with the viscosity agents. Besides, all fresh SCC properties satisfy the EFNARC SCC Specification [17].

Consequently, it can be said that RA improves the workability of SCC produced with different viscosity agents.

Furthermore, they showed if the mechanical and durability properties of hardened SCC are considered, the usage amount can also be said as 180 kg/m^3 content again. Concrete compressive strength and durability properties decrease with increasing RA content in the mixture (Fig. 3). Besides, the residual compressive strengths after high temperature (400°C and 800°C) (Fig. 4, 5) and freezing–thawing effects also decrease (Fig. 6). On the other hand, the obtained values are still higher than those of ordinary concretes mixed with similar amounts of RA. Finally, it can be said that RA in SCC decrease the mechanical and durability properties of ordinary SCC. However, the performance of RSCC is still better than ordinary concretes.

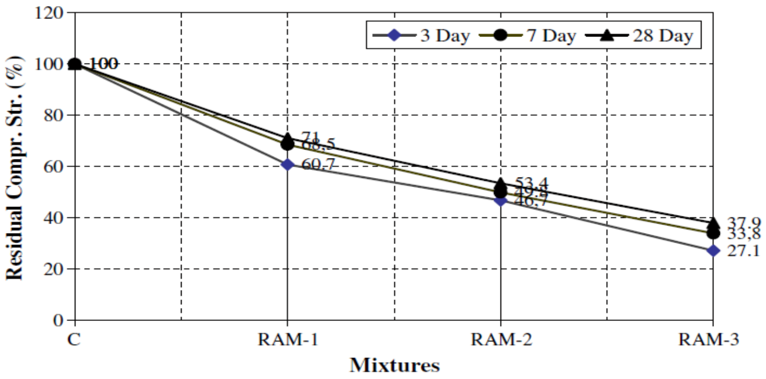


Fig3- The compressive strengths with respect to increased RA [16]

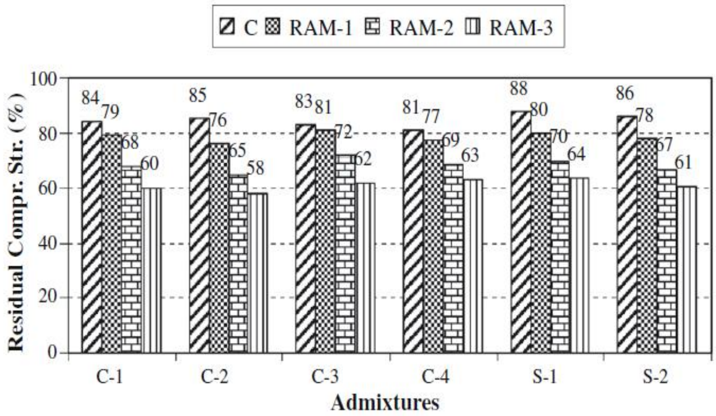


Fig4- The compressive strengths of specimens exposed to 400 °C [16]

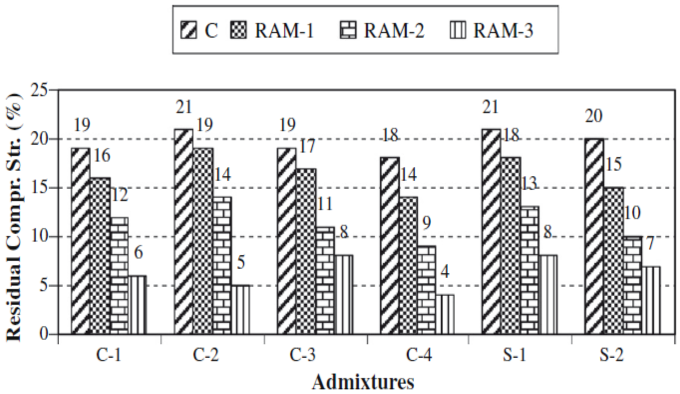


Fig5- The compressive strengths of specimens exposed to 800 °C [16]

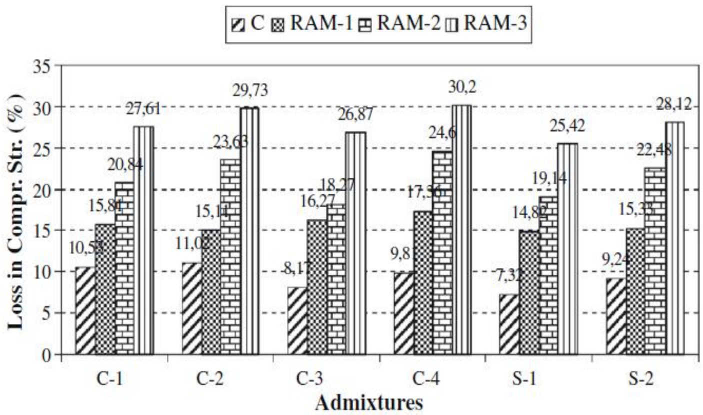


Fig6- Residual strength after freezing and thawing test [16]

According to the results of their study, the optimum usage RA content in SCC can be said as 180 kg/m3 in order to obtain sufficient performance for both of fresh and hardened properties of SCC.

In the investigation of Erhan Guneyisi [18] entitled “Fresh properties of self-compacting rubberized concrete incorporated with fly ash”, the usability of untreated crumb rubber as a partial substitute of fine aggregates with and without fly ash in the application of self-compacting concretes was investigated experimentally. For this purpose, a water–cementitious material ratio (0.35), four designated crumb rubber contents (0, 5, 15, and 25% by fine aggregate volume), and four fly ash content (0, 20, 40, and 60%) were considered as experimental parameters. Test results indicated that use of crumb rubber (CR) without fly ash (FA) aggravated the fresh properties of self-compacting rubberized concretes (SCRC) (slump flow diameter, T50 slump flowtime, V-funnel flow time, L-box height ratio, initial and final setting times, and viscosity). However, the use of CR with FA amended the fresh properties of SCRC. Based on the findings of their study, the following conclusions obtained:

- Using CR increased the need of superplasticizer of the mixtures as well as T50 and V-funnel flow times of the produced concretes, while using FA resulted in a steady decrease at the T50 and V-funnel flow times of the concretes with respect to the concretes without FA.
- While the use of CR remarkably increased the viscosity of the SCRC, use of FA decreased the viscosity. Concretes containing both CR and FA diminished the negative effect of CR and decreased the viscosity of concretes.
- The test result of compressive strength showed that using the CR and FA declined the compressive strength of SCRC dramatically, and the rate of reduction grew with increasing of CR and FA content.

Permeability properties of self-compacting rubberized concretes were released by Mehmet Gesoğlu [19] and his co-workers.

They considered the self-compacting rubberized concretes with fly ash and without it. They selected water–cementitious material (w/c) ratio of 0.35. By replacing the fine aggregate with four designated crump rubber contents of 0%, 5%, 15%, and 25% by fine aggregate volume, the self-compacting concretes (SCCs) were made. Moreover, the SCCs with fly ash were produced by partial substitution of cement with fly ash at varying amounts of 20% to 60%.

According their published article, the chloride ion penetration saw an increase with the increasing the rubber content, especially for the concretes without fly ash.

The chloride ion permeability test results as a function of crumb rubber and fly ash contents as well as testing age are illustrated in figure 7. The figure shows that the chloride ion permeability of the SCRCs were in the range of 1904 to 3460 C and 476 to 3139 C at 28 and 90 days, respectively.

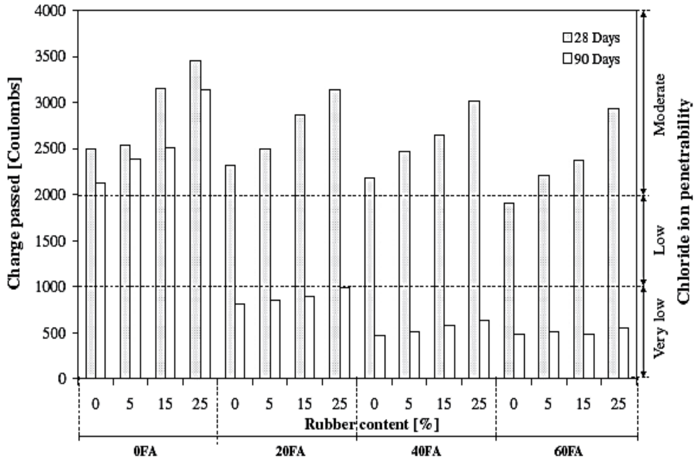


Fig7- Chloride ion permeability variations of self-compacting rubberized concretes with crumb rubber and fly ash contents [19]

As fig. 7 claims, incorporating fly ash did not cause a considerable drop in the chloride ion permeability of the concretes at 28 days.
In addition, their paper presented the sorptivity coefficients of the self-compacting rubberized concretes depends on the contents of crumb rubber and fly ash as well as testing age. In figure 8 a highlighted increase can be seen in sorptivity with increasing the rubber content.

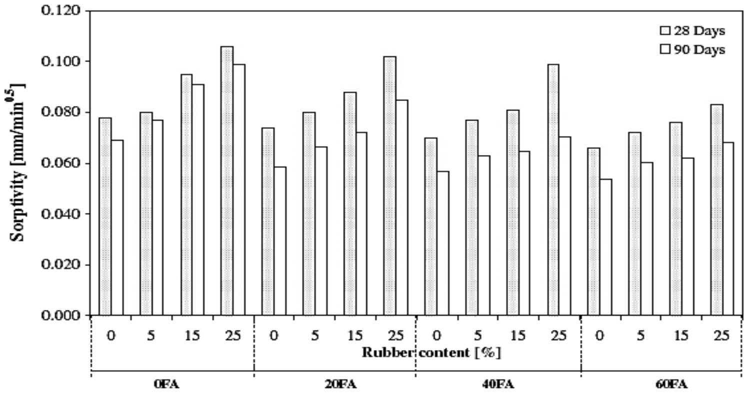


Fig8- Water sorptivity variations of self-compacting rubberized concretes with crumb rubber and fly ash contents [19]

They also found the relationship between the chloride ion permeability and sorptivity of the concretes. Figure 9 illustrates that chloride ingress of the concretes is strongly related to the sorptivity, especially at 28 days.

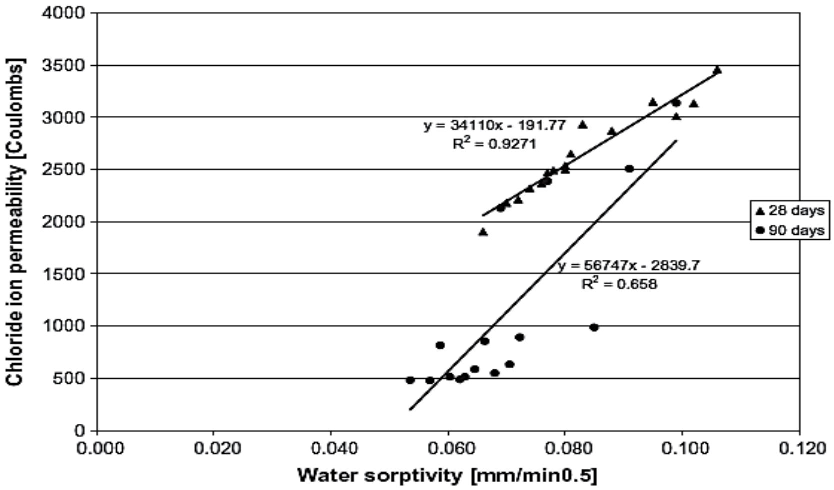


Fig9- Relationship between chloride ion permeability and sorptivity [19]

Based on their results, water absorption of the SCRCs tested as per ASTM C 642 [20] is depicted in figure 10. It claims that the water absorption of the concretes varied from 2.73% to 4.25% and from 2.56% to 4.03% at 28 and 90 days depending on the crumb rubber and fly ash contents, respectively. In other words, using of crump rubber made the concretes more absorbent with an increasing rate with the crump rubber content.

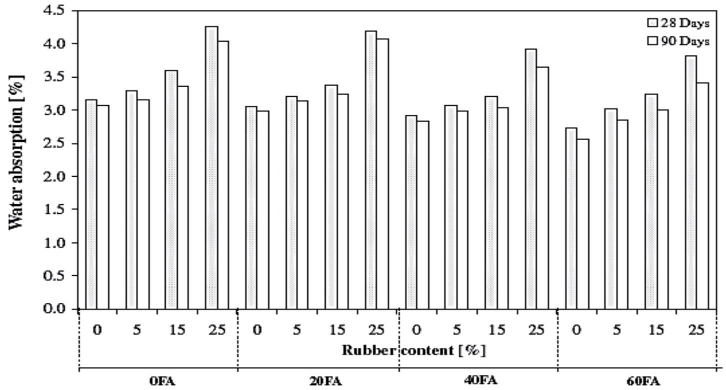


Fig10- Water absorption variations of self-compacting rubberized concretes with crumb rubber and fly ash contents [19]

Finally, they showed the relationship between the chloride ion permeability and water absorption of the concretes for 28 and 90 days in figure 11. As can be seen in figure11, chloride ion permeability of the concretes was significantly influenced by the amount of water absorbed.

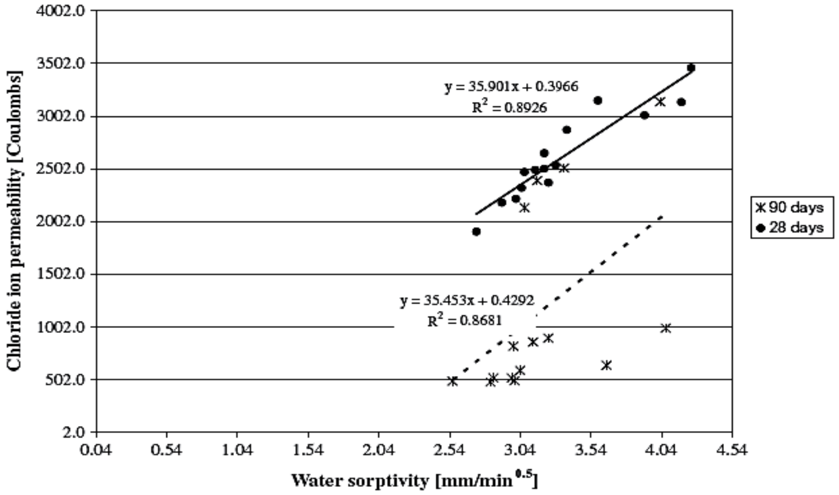
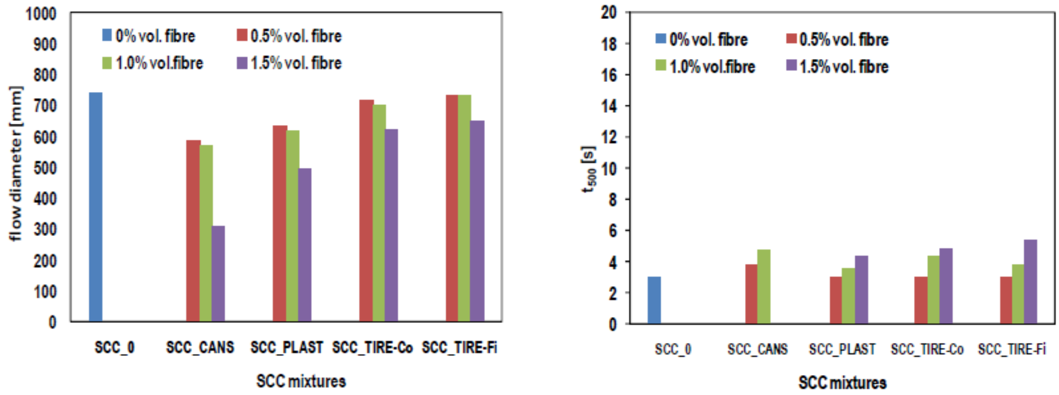


Fig11- Relationship between chloride ion permeability and water absorption [19]

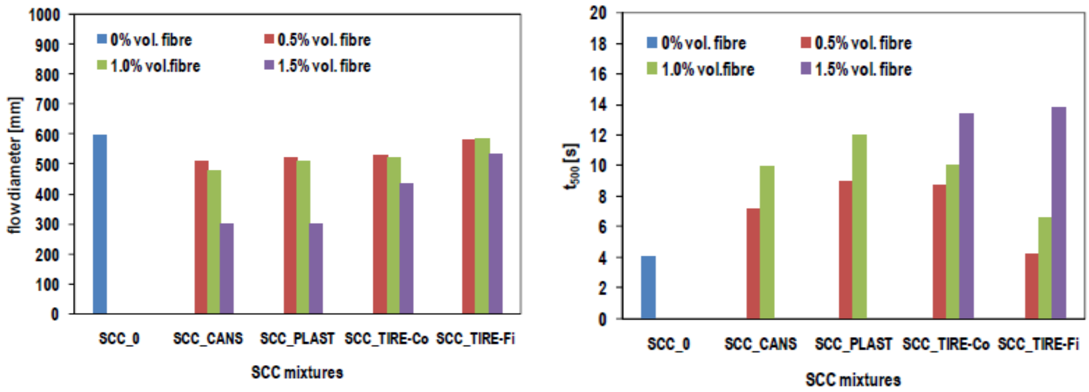
SholihinAs'ad and his collogues [21] held an experiment with the aim of getting the fresh state behavior of self-compacting concrete containing waste material fibers such as, plastic bottle, rubber tire and alloy cans. 0.47 was selected as water cement ratio of SCCs. The samples were added micro size (fine tire fibre) and macro (coarse tire fibre) size of rubber fibre, alloy can fibre and plastic bottle fibre with 0, 5 %, 0,1 % and 1,5 % of vol. fibre dosage respectively. Also the macro size fibres were about 35 of fibre aspect ratio (length/diameter).

From the experimental results of this investigation, the following conclusion can be drawn:

- Fibre type and fibre dosage are factors that influence of the fresh state behavior of SCC. As fibre distributed on the space among the aggregate and fine component of SCC, its interlock with aggregate will reduce the SCC deformability. The stiffer waste fibre material makes stronger fibre-aggregate interlock and consequently develops higher resistance against SCC flow. The higher fibre dosage, the higher fibre-aggregate interlock that resists much SCC flow. This effect decreases the flow spread distance, increases flow time and tend to form blocking on reinforcement bars. Fiber decreases SCC flow-abiliy, passing-ability and self-leveling ability (Fig.12)



Slump flow test



J-Ring test

Fig12-Influence of fibre type and dosage on the SCC flow diameter and t500 of slump flow and J-Ring test [21]

- The flow behavior of fresh plain SCC will change by the waste material fibre addition. The flow pattern tends to be non-homogen due to non-homogen distribution of fibre-aggregate interlock resistance. By obstruction of reinforcement bar, the blocking potentially occur since the stiffer fibre generally creates coarse aggregate interlocking. However this effect is less on the flexible waste material such tire since it is flexible and easy to deform on the space of inter-aggregate of SCC (Fig.13).

a: SCC without fiber　　　　b: SCC with 1% plastic fiber

Fig13- SCC spreads non-homogeneous and shows blocking effect since the restriction of stiff fibre [21]

- Mixture of SCC with fine rubber tire fibre recorded the best performance on flowability, passing ability, self-leveling compared to other SCC with fibres. This is because of it is made flexible and finer form that allow it easy and flexible to deform in inter-space of SCC aggregate (Fig.14).

(a) SCC with 1% fine tire fibre (b) blocking SCC 1% cans fibre (c) blocking on U-box test

Fig14- Suitable flow and blocking on bar of L-box and U-box of SCC due to stiff fibres [21]

- The filling ability of SCC cost much time when waste material fibre is added into it. However, the fibre type does not much change the filling ability. It is important to find a detail trend by further observation with higher fiber dosage. (Fig.15)

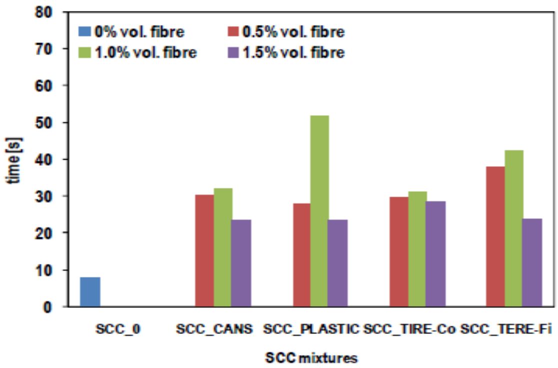


Fig15- Influence of fibre type and fibre dosage on the flow fime of SCC [21]

In Khalid B. Najim and his research team's study [22], the mechanical and dynamic properties of self-compacting rubberized Concrete (SCRC) were experimentally investigated.
A petty part of Fine Aggregate (FA), Coarse Aggregate (CA) and composed Fine and Coarse Aggregate (FCA) at 5, 10, and 15 wt.% proportions were replaced by Crumb rubber.
At the end, they concluded that:
- Self-Compacting Rubberized Concrete (SCRC) has supreme dynamic properties to plain mixes. It also has sufficient mechanical properties for structural applications (fc > 17 MPa; q > 2000 kg/m3).
- The flexural strength declined by Crumb rubber aggregate replacement, but this substitution was the cause of remarkable increase in strain capacity which led to reduce the Crack Mouth Open Displacement (CMOD), which is significant in terms of serviceability.
- The Young's modulus of elasticity (E) experienced a decrease for all SCRC samples, but flexural toughness improved, so this improvement was the cause of improving the ductile behavior and energy absorption.
- When dynamic response and vibration damping are a preference SCRC mixes play a significant role for specialist applications.
- E_d was greater than 32 GPa for all replacement amounts although it decreased with wt% rubber substitution.
- Good quality rating could be defined at up to 15 wt% (260 kg/m3 rubber aggregate) for all replacement types, and UPV measurements can be used as a non-destructive measure to evaluate the quality of SCRC mixes.
- SCRC mixes show great vibration damping behavior, com- pared to SCC and NVC mixes, where both the damping ratio and damping coefficient were improved by roughly 230% for SCRC (CR15%) mix.

Wang Her Yunga and his research group [23] studied the durability properties of waste tire rubber applied to self-compacting concrete.
The self-compacting rubber concrete (SCRC) was produced by replacing part of the fine aggregate by waste tire rubber powder filtered through #30 and #50 sieves.
Their published results can be found as below:
- When 5% of the waste tire rubber powder that had been passed through a #50 sieve was added (increased by 1–10%) the compressive strength of SCRC experienced its best situation (Fig.16).

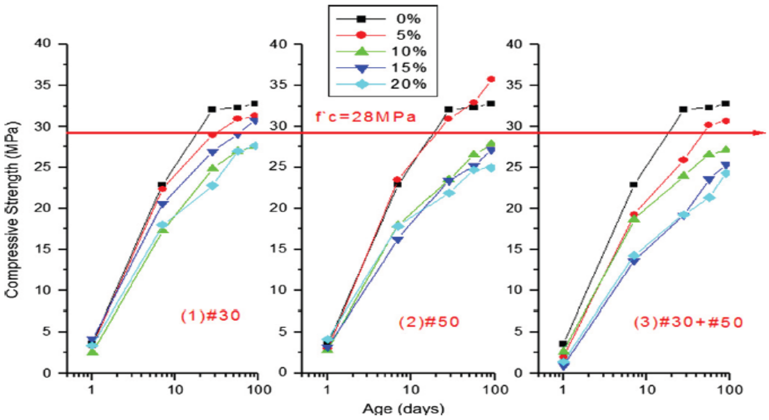


Fig16- Compressive strength for SCRC [23]

- When 5% waste tire rubber powder was added the 28 days ultrasonic pulse velocity was 4000 m/s and that of the other samples were more than 4000 m/s. However, after adding more, it declined to less than 4000 m/s. Because the average waste tire rubber powder that had been passed through a #30 sieve was 6.5% lower than the control group, this indicated that the ultrasonic pulse velocity would decrease with an increase in the amount of waste tire rubber powder.(Fig.17)

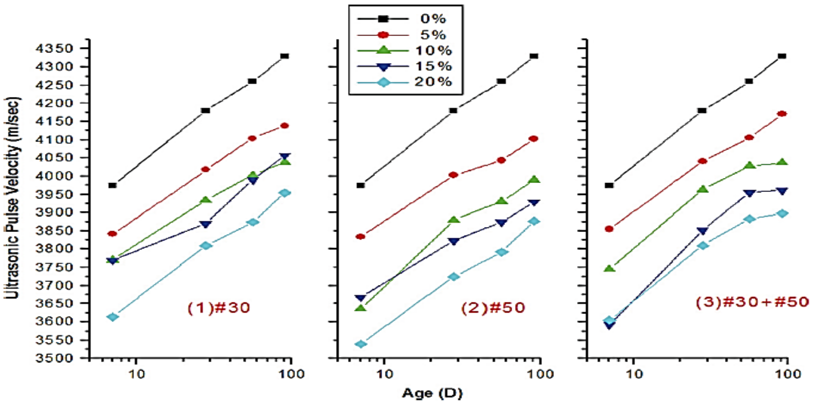


Fig17- Ultrasonic pulse velocity for SCRC [23]

- Compared with ordinary concrete the concrete with rubber powder shrinkage of was small, and its length grew when more rubber powder was added. It increased 35% and 95% in length by 5% and 20% addition of powder respectively (Fig.18).

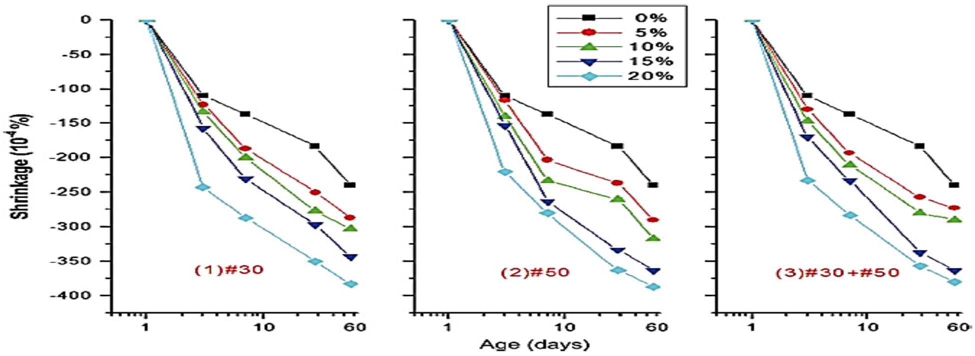


Fig18- Shrinkage for SCRC [23]

- Adding waste tire rubber powder that had been passed through a #30 sieve increased the surface resistance by 17%, so the SCRC had relatively high electrical resistance properties. (Fig.19)

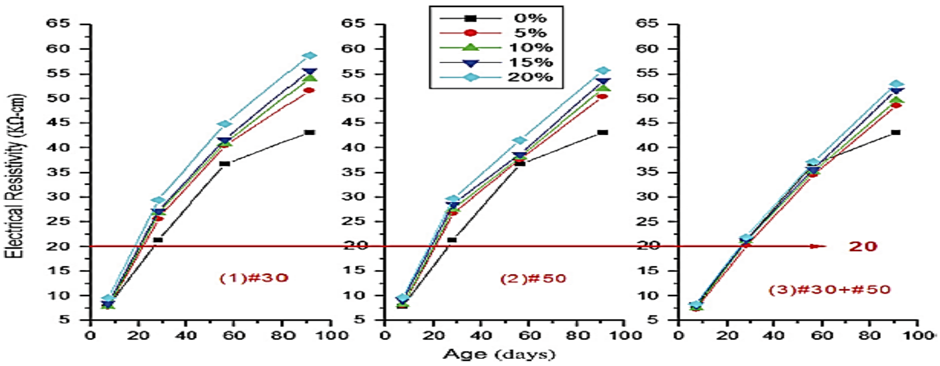


Fig19- Electrical resistivity for SCRC [23]

- Taking the fifth recycling as an example, 5% waste tire rubber powder had the least weight loss, and adding waste tire rubber powder that had been passed through a #30 sieve led to anti-sulfate corrosion resistance (Fig.20).

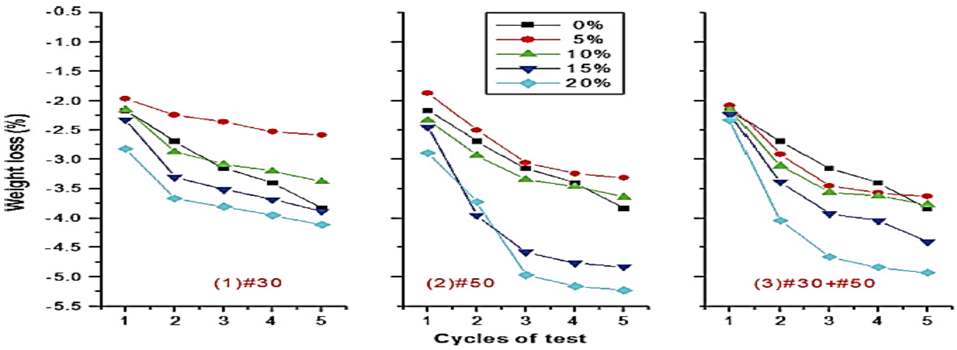


Fig20- Weight loss for SCRC immersed in sodium sulfate solution [23]

- Finally, they claimed that the best level of replacement is adding 5% waste tire rubber powder that had been passed through a #50 sieve.

The N. Ganesan and his co-workers [24] paper illustrates the flexural fatigue behavior of Self Compacting Rubberized Concrete (SCRC) with and without steel fibers.

They replaced the fine aggregate by shredded rubber, viz. 15% and 20% and volume fraction of steel fibers, viz. 0.5% and 0.75%, and all samples were tested under fatigue loading considering maximum stress levels ranging from 90% to 60% of the static strength. (Fig. 21)

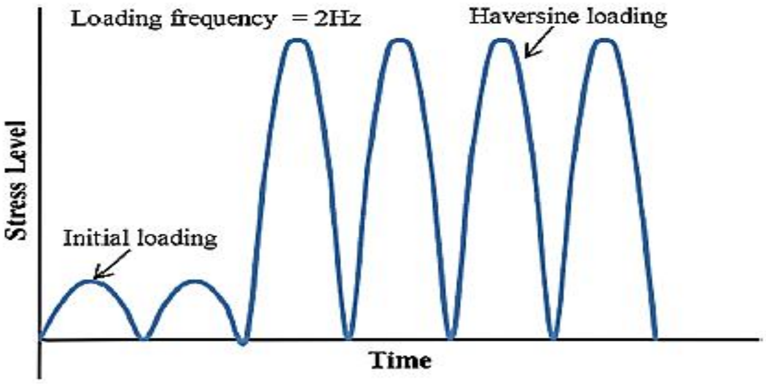


Fig21- Loading pattern [24]

The following conclusions were arrived at:
- The fatigue strength of SCC grew by approximately 15% due to adding scrap rubber, and it continues its trend by increasing the rubber content.
- Adding the crimped steel fibers to SCRC was the cause of enhancing the fatigue strength by roughly 25–50%. By increasing steel fiber volume fractions the amount of fatigue strength in percent reached to13% which was a highlighted improvement.
- The shape parameter for the fatigue life data of SCC, SCRC and SFRSCRC increased with decrease in stress level, thus indicating lower variability in the fatigue life distribution of SCC, SCRC and SFRSCRC at lower stress levels. At the same stress level, the shape factor was seen to decrease with increasing rubber content as well as increasing steel fiber volume fraction, resulting in higher variability in the fatigue life of SCRC and SFRSCRC at higher rubber contents and higher steel fiber volume fractions.

Eehab Khalil et al [25] in their paper in titled “Impact Resistance of Rubberized Self-Compacting Concrete” realized that when the percentage of rubber grew, the resistance to impact increased unlike specimen strength and modulus of elasticity, they declined.

Concrete samples were produced with different crumb rubber ratios of 10% (RSCC-10), 20% (RSCC-20), 30% (RSCC-30), and 40% (RSCC-40) sand replacement by volume.

They finally published their results as can be seen below:
- The mix RSCC-30 (crumb rubber ratios of 10%) exhibited the best impact resistance, 3 times over control mix with 40% reduction of compressive strength. Rubberized concrete show some promising behavior against impact loading.
- The increase in amount of rubber content was the reason of decreasing the compressive strength.
- At the end of their investigation, they suggested these kinds of concretes to cover a variety of construction material used in structures subjected to impact loading.

E.Güneyisi and his research team [26] during their investigation about evaluation of the rheological behavior of fresh self-compacting rubberized concrete by using the Herschel–Bulkley and modified Bingham models could achieve the following results.
- The gained results from the remoter showed that the replacement of the natural aggregate with rubber particles needed higher torque at the same rotational speed. In particular, the torque values grew dramatically with the tire chips utilization.
- The shear thickening behavior when the Herschel–Bulkley and modified Bingham models were applied was demonstrated by the made self-compacting rubberized concretes.
- The data from the Herschel–Bulkley and modified Bingham models presented that the utilization of rubber rather than natural aggregate resulted in enhancing the exponent 'n' (the Herschel–Bulkley) values and 'c/m' (the modified Bingham) coefficients, respectively. Besides increasing the rubber content from 0 to 25% went up systematically these values, which are the exhibition of shear thickening.

- The highest exponent 'n' values and 'c/m' coefficients were gained when the natural coarse aggregate was replaced with tire chips while the lowest values were gained when the natural fine aggregate was replaced with No.18 crumb rubber at each replacement level. (Fig.22)

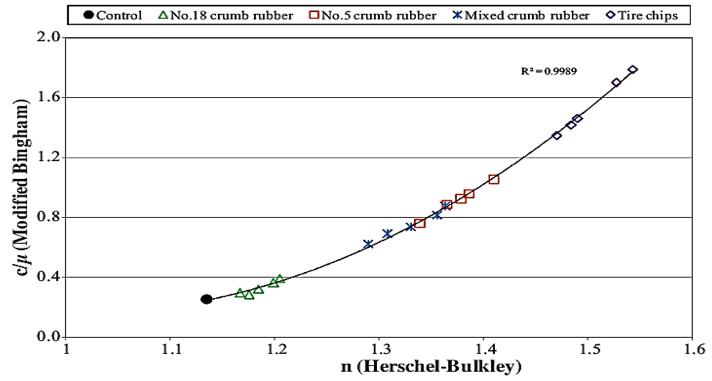


Fig22- Relationship between c/m and n coefficients [26]

- Replacing the natural aggregate with waste rubber decline the compressive strength was clarified according to compressive strength tests. However, it was seen that the compressive strength more than 30 MPa could be gained in the self-compacting concrete including 25% crumb rubber or tire chips. (Fig.23)

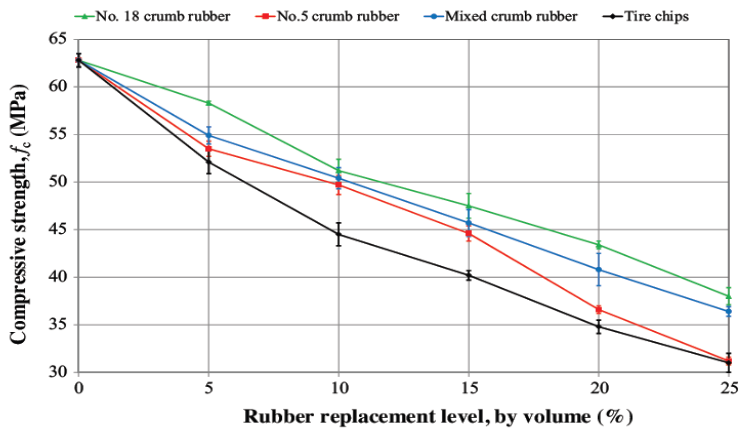


Figure23-Variation in the compressive strength with respect to rubber replacement level [26]

Saeid Hesami and his co- workers [27] studied on the mechanical behavior of self-compacting concrete pavements incorporating recycled tire rubber crumb and reinforced with polypropylene fiber. Then they clarified that:

- Increasing fiber amount and TRC in concrete leaves a negative impact on rheological properties of self-compacting concrete.
- Although addition of fiber up to 0.1% grows the compressive strength, it decline the compressive strength of SCC at the age of 28 days because aggregates are expected to bear the higher level of loads than rubbers and also the adhesion between TRC and paste is weaker than that between aggregate and paste. (Table 3)
- Increasing the sand replacement with rubber led to decline the tensile strength. Also after 15% sand replacement with rubber the compressive strength decreased 14.29% because the tensile fracture mode in concrete containing fiber is different from tensile fracture mode of normal concrete. (Table 3)
- Replacing the aggregate with TRC decreases the modulus of elasticity. The tests illustrate that presence of fiber does not have noticeable impact on modulus of the elasticity of concrete and only highlighted growth is clarified. (Table 1)
- The flexural strength also decreases when the amount of rubber as a sand replacement grows. 15% sand replacement with TRC, when no finer is used, leads to a 17% decrease in flexural

strength. However, addition of fiber can improve the flexural strength after the formation of cracks. (Table 2)

Table1- Result of hardened concrete test [27]

Series	*MIX No.*	*Compressive strength (MPa)*	*Tensile strength(MPa)*	*Modulus of elasticity(GPa)*	*Flexural strength(MPa)*
A	1	78.05	4.90	42.53	8.45
A	2	79.65	5.85	44.65	10.66
A	3	74.53	6.27	46.39	11.24
A	4	-	-	-	-
B	1	68.12	4.82	40.21	8.03
B	2	73.21	5.70	43.74	9.94
B	3	70.07	6.08	44.09	10.74
B	4	-	-	-	-
C	1	59.94	4.63	38.56	7.48
C	2	68.55	5.54	41.26	9.49
C	3	66.10	5.90	42.76	10.02
C	4	-	-	-	-
D	1	55.15	4.20	35.03	6.98
D	2	67.21	5.09	36.45	8.45
D	3	54.01	5.33	37.59	9.14
D	4	-	-	-	-

- Increasing the rubber percentage from 0 to 15%, when 0% fiber is used, increases the water absorption by 26.47% while addition of fiber decline water absorption. (Table 2)

Table2- Results of water absorption test, ultrasonic wave test and abrasion resistance [27]

Series	*MIX No.*	*Water Absorption (%)*	*Ultrasonic Pulsevelocity (m/s)*	*Index of Abrasion resistance*
A	1	1.36	5128.00	1.31
A	2	1.18	4615.70	1.58
A	3	1.15	5431.50	1.78
A	4	-	-	-
B	1	1.49	4871.50	1.28
B	2	1.27	4579.50	1.43
B	3	1.19	4420.20	1.61
B	4	-	-	-
C	1	1.60	4728.20	1.15

C	2	1.40	4533.90	1.30
C	3	1.26	4387.50	1.55
C	4	-	-	-
D	1	1.72	4539.00	1.03
D	2	1.50	4449.10	1.22
D	3	1.38	4322.90	1.50
D	*4*	-	-	-

- The velocity of ultrasonic wave is reduced when the rubber content in SCC increases. Also, increasing the polypropylene fiber led to a decline in the velocity of the ultrasonic waves.
- At the end, they concluded that abrasion resistance index of has a declining trend by the growth of rubber content or the reduction in the content of fiber. It can be stated that increase of TRC in SCC up to 15% has no considerable negative effect on some of the properties studies in this research. However, this effect can be compensated through adding a certain percentage of fiber to the mix.

Nahla NajiHilal [28] started to study about the hardened properties of self-compacting concrete with rubber at six different replacement levels of 0%, 5%, 10%, 15%, 20%, and 25% and prepared 16 samples. Based on the results obtained from the experimental program could conclude that:
- Using crumb rubber in self-compacting concrete could reduce the compressive strength. Also using the coarse crumb rubber increase the rate of decline more than using of fine crumb rubber.
- The control mixture had the highest splitting tensile strength, by increasing rubber content the splitting tensile strength declined systematically. (Fig.24)

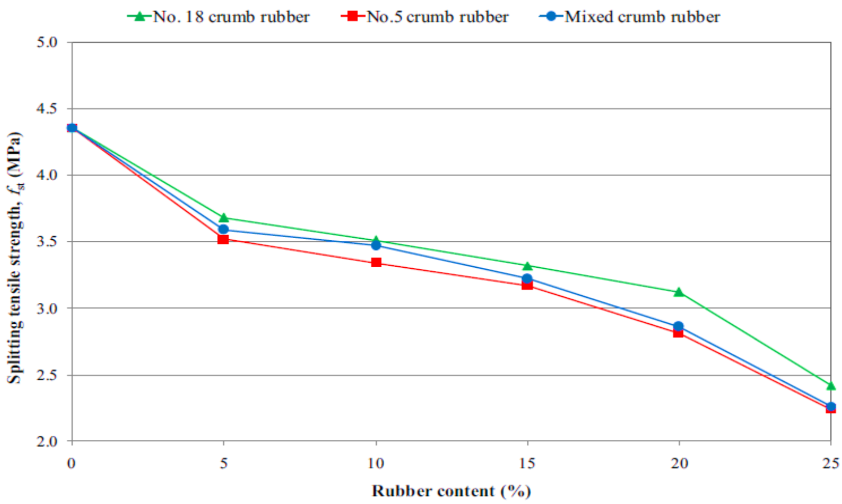


Fig24-Variation of 90-day splitting tensile strength with respect to crumb rubber size and content [28]

- The static elastic modulus reduced with the growing rubber size and content like that of in both compressive and splitting tensile strengths.(Fig.25)

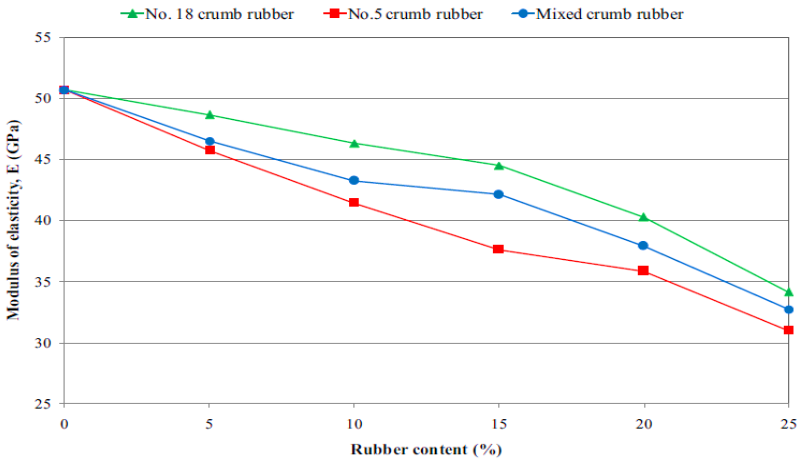


Fig25- Variation of 90-day Modulus of elasticity with respect to crumb rubber size and content [28]

- The highest value of the net flexural strength belongs to control mix. In other words, the control mix had greater net flexural strength compared to other mixture containing (Fig.26).

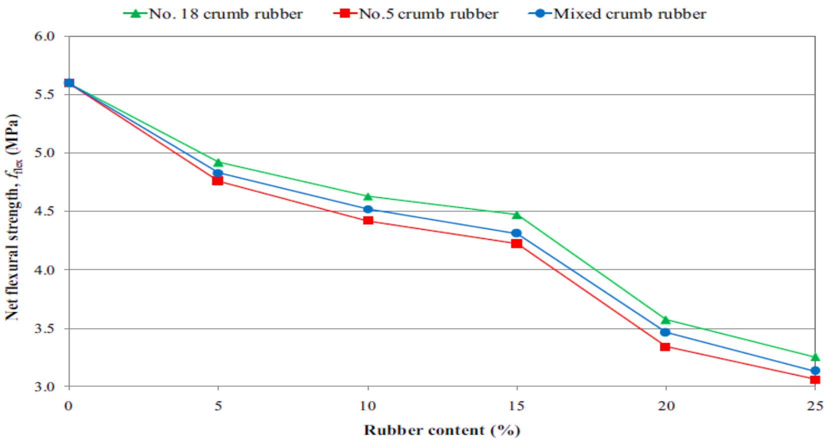


Fig26- Net flexural tensile strength with respect to crumb rubber size and content [28]

- Control mixture had the greatest fracture energy (GF), and it decreased by increasing the rubber content. The highest fracture energy value was gained when the natural fine aggregate was replaced with 5% crumb rubber, while the lowest value was obtained when the natural fine aggregate was replaced with 25% crumb rubber. The fracture energy worked the most efficient results for using crumb rubber. (Fig.27)

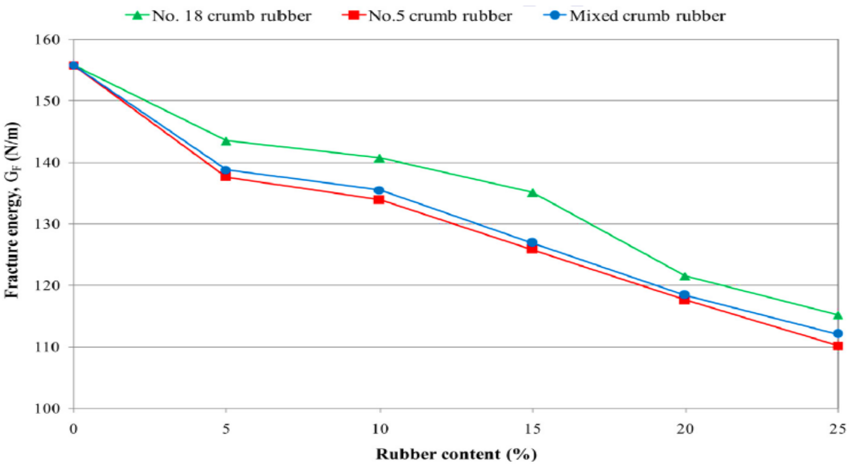


Fig27- Fracture energy with respect to crumb rubber size and content [28]

- The characteristic length, which is a measure of ductility of the concrete, was experienced a dramatic growth by increasing the crumb rubber volume fraction. While the significant improvement was gained with addition of all tire wastes types, the best result for ductility was achieved with 25% mixed crumb rubber. (Fig.28)

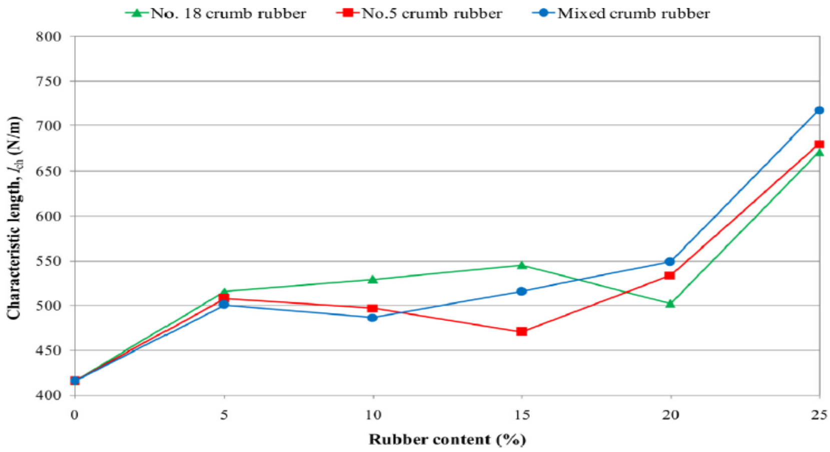


Fig28 - Characteristic length with respect to crumb rubber size and content [28]

- The maximum displacement corresponds to the maximum load, the highest maximum load for the control mix and decreases gradually according to the amount and size of crumb rubber respectively.
- Growing the crumb rubber size and content led to abating of bond strength. Furthermore, the bond strength of concrete with mixed crumb rubber (MCR) saw more improvement than in concrete with crumb rubber.

Farhad Aslani and his group worked [29]on experiment into rubber granules and their effects on the fresh and hardened properties of self-compacting concrete. Three different series of SCRC mixtures were produced with constant a w/b ratio of 0.45 and total cementations materials content of 450 kg/m3. The 1st and 2nd group had fine aggregates replaced with 2mm and 5mm sized crumb rubber. The 3rd group had coarse aggregates replaced with 10 mm sized crumb rubber. The three crumb rubber sizes were replaced at volume ratios of 10%, 20%, 30%, and 40%. In total, 12 different mixtures of SCRC were designed.

Their following conclusions can be drawn based on the experimental results documented in their paper as bellow.

- SCRC mixes illustrated poor passing ability because of the coarse and jagged CR aggregates. This could be improved by increasing fines content.
- All samples in which rubber aggregates were replaced at 10% gained compressive strength more than 30 MPa, and the maximum rate was 40.68 MPa.
- The 5 mm SCRC series showed the greatest compressive and tensile strengths of the three series, and the coarser 10mm aggregates produced the worst results.
- Increasing the size of CR aggregates demonstrated a growth in the maximum peak strains as evident in the results from the 2 mm and 5 mm SCRC series.

Farhad Aslani and his co-workers [30] in another investigation, did a research project on development of high-performance self-compacting concrete using waste recycled concrete aggregates and rubber granules. They released his result as bellow:

- The self-compacting mixes could decrease the usage of cement to 40%. In other word in all mixes 180Kg/m3 cement have used because recycled concrete, crumb rubber and scoria aggregates are used in them.
- The concrete density reduces by increasing the percentage of recycled aggregate replacement because the density of the recycled aggregates being less dense than the natural aggregates.
- A decline in the flow ability and passing ability was seen by growing the amount of recycled aggregate replacement during slump test diameter, the J-Ring test diameter, and height difference.

- An increase in the rate of coarse recycled aggregate demonstrated a decrease in compressive strength. The sample mix with 40% replacement showed 13% decline in compressive strength, so it was defined as the worst condition.

RuizheSi and his team [31] did a research about evaluation of laboratory performance of self-consolidating concrete with recycled tire rubber. They concluded that:

- The fresh properties of SCC mixture reduced by replacing the aggregates by rubber aggregates. However, NaOH treatment of rubber aggregate can slow the reduction in flow ability of SCC caused by rubber aggregate and also improve the rheological properties of rubber modified SCC.
- The compressive strength of rubber modified SCC declined by growing the rate of rubber aggregate, Compared with normal SCC. The SCC mixtures with NaOH treated rubber aggregate appeared to have slightly higher compressive strength than SCC mixtures containing as-received rubber aggregate. Furthermore, rubber modified SCC have reduced brittleness and improved ductility compared to normal SCC. (Fig.29)

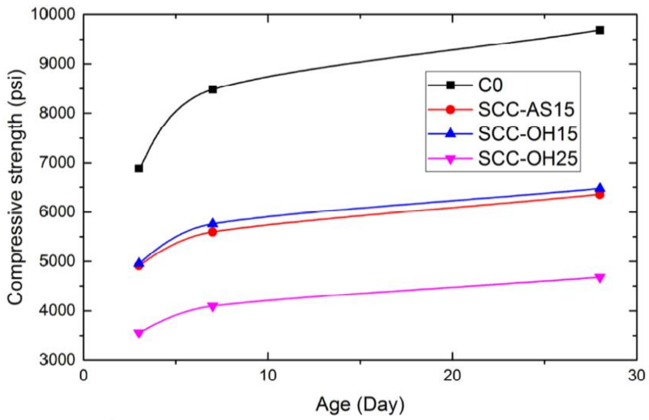


Fig29- Compressive strength of different types of SCC mixtures at various ages [31]

- By increasing the content of rubber in the mixture the splitting tensile strength of rubber modified SCC decreased. This rate improved 5.9% at the age of 28 days when the surface of NaOH in rubber aggregate treated. In same situation due to the ability of rubber aggregates in preventing some crack propagation in cement concrete mixture the reduction of the splitting tensile strength was less than that of compressive strength.(Fig.30)

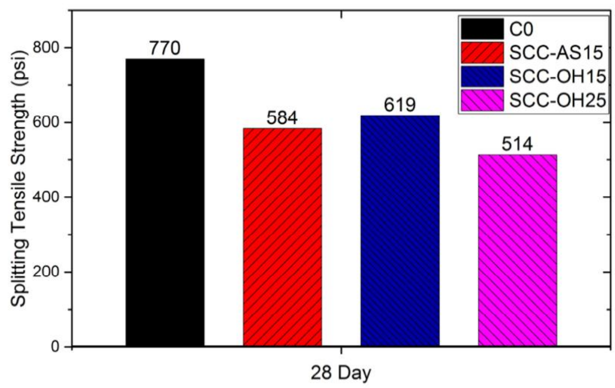


Fig30- Splitting tensile strength of different types of SCC mixtures at various ages [31]

- Electrical resistivity of SCC mixtures grew by adding rubber aggregate. The impact of NaOH-treated rubber aggregate was more effective on electrical resistivity property of SCC mixtures. When 15% and 25% NaOH treated rubber particles were mixed into concrete mixture the electrical resistivity was developed more than 50 %.(Fig.31)

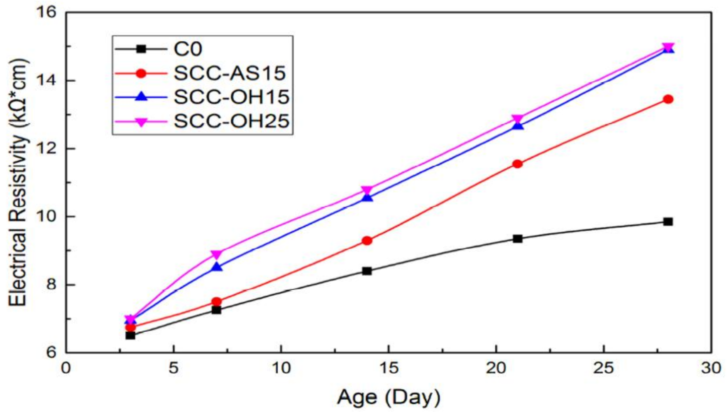


Fig31- Electrical resistivity of the SCC samples with different rubber aggregate contents [31]

- Added rubber affected the pore structure of SCC mixture, so by adding the rubber aggregate into SCC mixture, ultrasonic transmission speed decreased. The NaOH treatment of rubber aggregate could omit this reduction because the decrease in porosity around NaOH-treated rubber aggregate improved the elastic modulus of SCC mixture (Fig. 32).

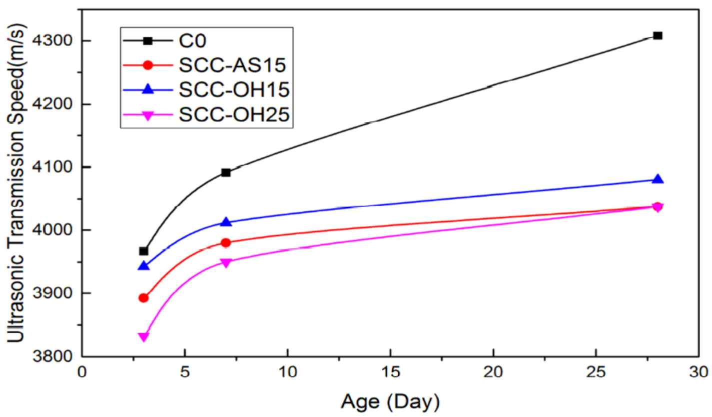


Fig32- The results of ultrasonic transmission speed measurement of the SCC samples with different rubber aggregate contents [31]

- The expansion and damage of SCC mixture during the ASR process reduce by introducing rubber aggregate. NaOH surface treatment of rubber aggregate decreased ASR expansion in rubber modified SCC by reducing the transport properties of the mixture and improving the rubber-cement bonding strength. The ASR expansion can be reduced by up to 23% in SCC samples with NaOH-treated aggregate compared with control SCC samples 21 days in age. (Fig. 33)

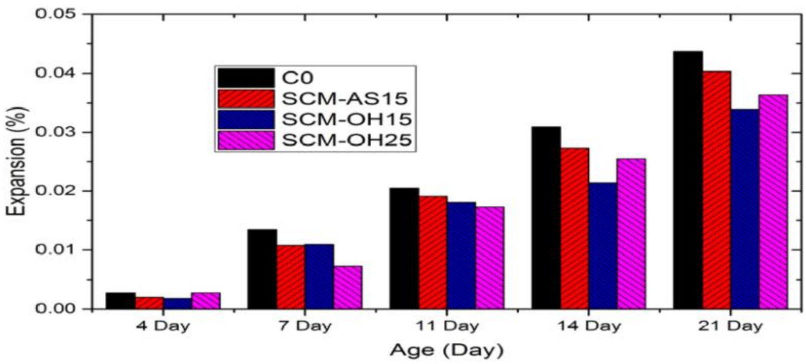


Fig37- ASR expansion of different types of SCC mixtures at various ages [31]

- Using the rubber modified SCC causes the slight growth in drying shrinkage. In addition, the increase in shrinkage decline with NaOH surface treatment of rubber aggregate in rubber modified SCC mixture. (Fig. 34)

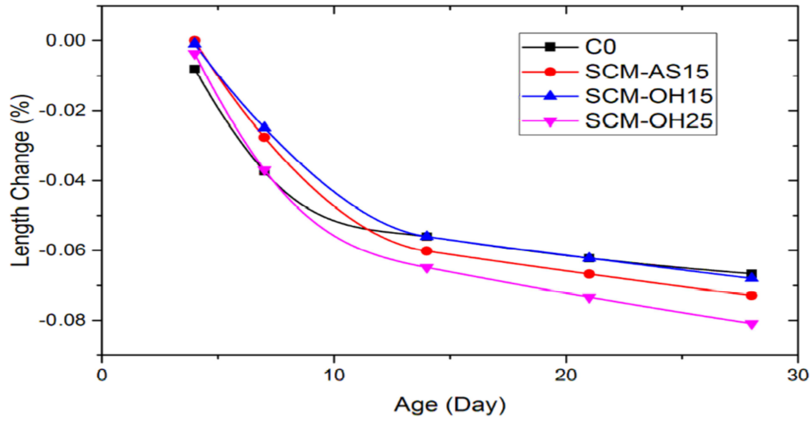


Fig34- Drying shrinkage of different types of SCC mixture at various ages [31]

3- Conclusion

Authors in this paper as a brief literature review studied the concept of utilization of waste tires in self-compacting concrete (SCC). All research works which are investigated clarified a number of positive and negative effects of adding or replacing waste tires into SCC. All researchers also demonstrated although waste tires could leave the negative impacts on SCC features, they cause some beneficial properties. Thus, using SCC mixed waste tires for special applications not only reduce the environmental degradation, but also has economic merits like reduction in cement or aggregates usage. The following conclusions could be obtained from the present investigation:

Positive Impacts:

- The flexural toughness improves in self-compacting rubberized concretes, and this improvement is the cause of improving the ductile behavior and energy absorption.
- In the case in which dynamic response and vibration damping are important, the self-compacting rubberized concretes are beneficial.
- Self-compacting rubberized concrete have high electrical resistance properties due to the increased surface resistance by adding more waste tire powders.
- Adding waste tire rubber powder into SCC led to anti-sulfate corrosion resistance.
- The resistance to impact in SCC increases by increasing the percentage of rubber, so this rubberized SCC is suggested to cover a variety of construction material used in structures subjected to impact loading.
- The exponent 'n' (the Herschel–Bulkley) values and 'c/m' (the modified Bingham) increases by using rubber instead of natural aggregates.
- The characteristic length, which is a measure of ductility of the concrete, experiences a sharp increase by increasing the crumb rubber volume fraction.
- Existence of waste tire in SCC could increase the fatigue strength of SCC roughly 15%.
- Self- compacting rubberized concrete has remarkable deformability before failure and capability to withstand post-failure loads with some further deformations.
- The optimum usage of rubber waste into SCC could be considered as 180 kg/m3. Also the usage of cement in rubberized SCC decreases approximately to 40% and reaches to nearly 180 kg/m3.
- Waste rubber is able to allocate the excellent dynamic properties to SCC.
- Substitution of aggregate with crumb rubber is the main cause of growth in strain capacity, and reducing the Crack Mouth Open Displacement.
- Generally, the rate of compressive strength, mechanical and durability properties of SCC with waste tires had been higher than that of ordinary Portland cement concretes with similar amounts of tire rubber wastes.

Negative Impacts:

- In all studies a decline in compressive strength of SCC is reported by increasing the amount of rubber waste in the mix. Some researchers also have claimed that using the coarse crumb rubber increase the rate of decline more than using of fine crumb rubber in SCC.
- The compressive strength declines when SCC samples with rubber wastes are tested after high temperature and freezing–thawing effects.
- SCC stiffness decreases with increasing amount of rubber phase, and similar to compressive strength this value is greater than ordinary concretes admixed with the same amounts of tire rubber wastes.
- Using crumb rubber in SCC increases the need of superplasticizer of the mixtures as well as T50 and V-funnel flow times, and it also significantly increases the viscosity of SCC.
- When the amount of crumb rubber grows, the penetration of chloride ion grows, too.
- The sorptivity coefficients of the self-compacting rubberized concretes increase sharply by growing the rubber content.
- The rheological properties of self-compacting concrete affects negatively by increasing the amount of waste tire.
- Fracture energy (GF) declines when the rubber content increases. Also this rate reaches to its maximum and minimum conditions at the 5% and 25% aggregate replacement by crumb rubber.
- Displacement which is related to the maximum load decreases gradually in order to increasing the amount and size of crumb rubber respectively.
- The SCC mixtures with NaOH treated rubber aggregate appeared to have slightly higher features than rubberized SCC without NaOH treated.
- Existence of waste tire in SCC could make it more absorbent towards water.
- By increasing the rate of waste tire in SCC mix, the durability experiences a decrease in its rate.
- Replacing aggregate with rubber could be cause of reduction in flexural strength of SCC.
- Modulus of elasticity (E) sees a reduction in self-compacting rubberized concretes with increasing the rubber size and content.
- Ultrasonic pulse velocity declines with an increase in the amount of waste tire rubber in SCC.
- The length of Shrinkage in rubberized SCC increases by adding more rubber powder, and the shrinkage in rubberized SCC is smaller than that of in ordinary concrete.
- When the sands are replaced by crumb rubber, tensile strength of rubberized self-compacting concrete experiences a decrease.

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