FUNDAMENTAL PROPERTIES OF SELF-COMPACTING CONCRETE UTILIZING WASTE RUBBER TIRES-A REVIEW

Sukamal Kanta Ghosh[1], D.K.Bera[2]

[1]*M. Tech Student, School of Civil Engineering. KIIT University, Bhubaneswar, Odisha, India*
[2]*Assistant Professor, School of Civil Engineering. KIIT University, Bhubaneswar, Odisha, India*

Abstract

Utilization of waste rubber tires in concrete technology is a popular research topic over the last two decades. Reuse of waste rubber tires in self-compacting concrete leads sustainable construction. Several studies have been conducted on incorporation of waste rubber tires in self-compacting concrete (SCC). This review paper draws general conclusions on fundamental properties of SCC by summarising and comparing many independent research works and justifies weather these waste tire aggregates are possible to utilize in self-compacting concrete or not . From the review it is evident that the waste rubber tire aggregates can be used in SCC as partial replacement of both coarse aggregates and fine aggregates. The result Although the mechanical properties of SCC experiences negative effect for introduction of waste rubber tire aggregates, still performance of rubberized SCC is better than ordinary SCC. Fresh properties of SCC incorporating rubber tire aggregates also is in acceptable limit.

KeyWords:*Waste rubber tire, Self-Compacting Concrete, Flowability, Passing ability, Compressive strength, Flexural strength, Dynamic elasticity of modulus, Water absorption, shrinkage.*

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1. INTRODUCTION

Over the last two decades Self-Compacting Concrete (SCC) described as the ‘‘most revolutionary step’’ in concrete technology due to its impact on environmental sustainability as well as economic sustainability in the construction industry [1]. SCC is a special type of concrete which possess the ability to self-compact under its own weight without any vibration i.e. no compaction is needed in SCC construction [2]. It offers high durability, high compressive strength and low permeability [3-5] as well as high flowability, filling rate and segregation resistance compare to ordinary concrete [6]. It also eliminates the noise and cost related to the compaction machineries and decrease man power. SCC is more applicable where structural components are designed with congested and close spaced reinforcement or structure of irregular geometry [28].

On the other hand the worldwide rapid growth of automobile industry generates a huge number of waste tires. USA and japan alone generated 270 million and 110 million waste or scrap tires annually [7]. Since waste tires leads many environmental threats, the disposal of these waste tires is necessary. But as these are not biodegradable, the ways of decomposing either by burning them or landfill disposal and both are harmful for environment. So the effective reuse or recycling of waste tires is a very essential issue.

This situation calls for an innovative solution of disposal of waste rubber tires by using them in construction industry. From the last two decades the reutilization of waste tires as a construction material gaining popularity. The concrete made with rubber tires known as rubberish concrete or rubberized concrete. Many researchers have been utilized different kind of waste tires by replacing them with natural aggregates in concrete. These studies ensures that rubber tires significantly improve concrete properties such as Ductility, abrasion resistance, vibration absorption, damping capacity etc. though the overall strength is decreased [8-19]. So tires can be used in SCC. The purpose of this paper is to review the leading studies which have been conducted on ‘Self-compacting concrete’ using ‘waste rubber tires’ and generalized a conclusion on influence of rubber materials on the properties of SCC.

2. WASTE RUBBER TIRE

2.1.Composition of rubber tyre

- Rubber/Elastomers
- Carbon Black
- Metal
- Textile
- Zinc Oxide
- Sulphur
- Additives
- Carbon-based materials

2.2.Properties of Rubber Tires

2.2.1. Strength

Tensile strength of rubber is high as Rubber is very flexible. It is highly durable, even after a rubber tire goes through the vulcanization process.

2.2.2. Bonding

It has a good bonding quality so that it could be easily bonded with other construction materials.

2.2.3. Thermal insulation

Waste rubber tires has good thermal conductivity [39]. So rubber tires are good insulator of heat hence a promising building material.

2.2.4. Acoustic insulation

Rubber tire has poor acoustic conductivity. So it is a good acoustical insulator.

2.2.5. Light weight

Since the weight of rubber is light so it can be used for preparing light weight construction materials. The specific gravity of rubber tire ranges from 1.02 to 1.27 [21, 22].

2.2.6. Water absorption

Water absorption tire rubber aggregates ranges between 2 to 4% [23].

2.3. Classification of rubber aggregates

2.3.1. Shredded or chipped tire rubber: Tire chips or Shredded rubber generally used ascoarse aggregate and has been partially replaced it for natural gravel [24, 38].

2.3.2. Crumb rubber aggregate: The size of crumb rubber is generally ranges between 4.75 and 0.425 mm. most of the researchers used it as a partial replacement of natural sand i.e. fine aggregate[8-19, 24,27,28,29,30,32,33 34, 38, 42].

2.3.3. Grounular tire rubber: It is the rubber aggregate which passes through 0.425 mm sieve. Some researchers utilized it in SCC mix[24].

2.3.4. Fibre rubber aggregate: Some of the researchers used shredded rubber as short fibre, generally from 8.5 to 21.5 mm in length with an average of 12.5 mm [25], and in the form of 68 mm long strips. [26]

3. PROPERTIES OF SCC USING WASTE RUBBER

3.1. Flowability (Filling ability)

SCC must be able to flow and fill into all the spaces within the formwork under its own weight. So the flowability which is related with workability is one of the foremost property of self-compacting concrete. According to 'The European Guidelines for Self-Compacting Concrete (2005)' 'Slump –flow' test is a test to assess the flowability of SCC in the absence of obstructions and 'V-funnel test' is for measure the flow time of SCC.

M.C. Bignozzi et al (2006) used 0, 22.2 and 33.3 % grinded crumb rubber (0.05-0.7 mm) as substitutions of fine aggregates by volume and reported that the addition of 22.2% crumb rubber has no effect on slump flow valueaddition of 33.3% crumb rubber [27].

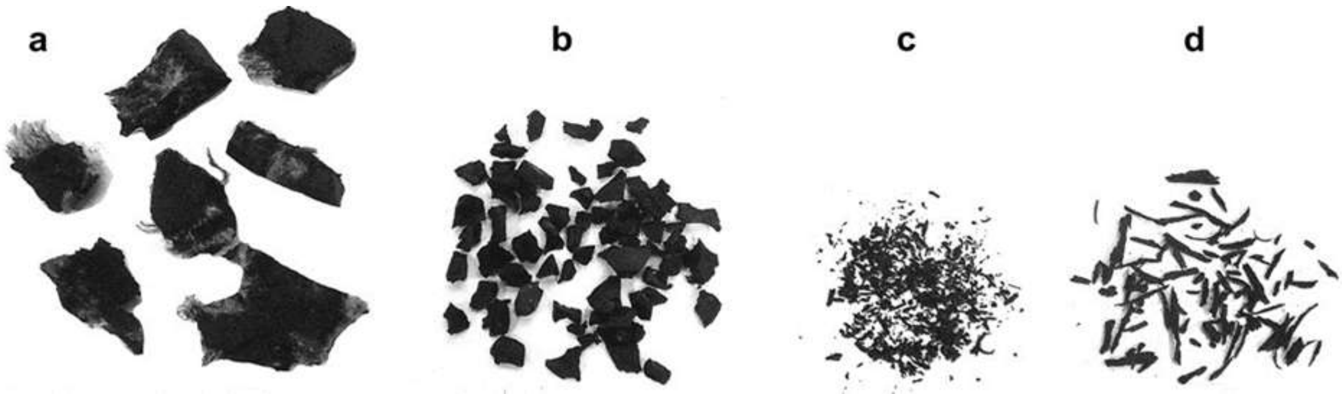

Fig -1: Classifications of rubber aggregates: (a) chipped rubber, (b) crumb rubber, (c) granular rubber (d) fibre rubber.

Eehab Khalil et al (2015) conducted tests on SCC samples with different crumb rubber (max. 2 mm) ratios of 10%, 20%, 30% and 40% sand replacement by volume. According his test data flowability(slump test value) decreased 11.5% for 0% to 40% rubber content replacement [28].

Ilker Bekir Topçu et al (2009) replaced aggregates with rubber contents of 60, 120 and 180 kg/m^3 in SCC by weight. The result of the test conducted by them indicated flowability slightly increased with the increase of rubber contents with different admixtures. The slump flow test data shows the flow diameters are between 69 and 80 cm. V funnel test results with various percentage of rubber content is also more or less in acceptable limit and the V-funnel flow time varies from 4.37 to 15.25 sec [29].

Tayfun Uygunoglu et al (2010) investigated the property of SCC by replacing sand with different scrap rubber (1-4 mm) ratios 0%, 10%,20%, 30%, 40% and 50% (by weight of sand) subject to various w/p ratio. He concluded increasing the rubber content results decrement in the slump flow of the mixtures. According to his result slump flow values varies from 110 to 230 mm in SCC mixture adding a rubber content of 50% subjecting on various w/p ratios. The V-funnel flow time improved considerably with increment of rubber content for w/p ratio of 0.47 [30].

N. Ganesan et al (2012) replaced sand by shredded rubber of 15% and 20% and volume fraction of steel fibres. He concluded that the slump is decreasing with increasing amount of rubber content. But the slump is more decreased when steel fibres are incorporate with these rubber modified SCC. V-funnel time is increased for adding rubber content in SCC [36].

E. Güneyisi et al (2016) utilized crumb rubber and tire chips, to partially replace the fine and coarse aggregate on SCC mixes at various level. According his test results the slump flow diameter of SCC with crumb rubber (i.e.680-750 mm) is higher than of tire chips (i.e 560-710 mm) [38].

3.2. Passing ability

It is the ability of fresh concrete to flow through congested openings, such as close spaced steel reinforcing bars without any blocking or segregation. According to '**The European Guidelines for Self-Compacting Concrete (2005)'** passing ability should be measured by **'L-Box'** test and **'J-Ring'** test.

M.C. Bignozzi et al (2006) used 0, 22.2 and 33.3 % grinded crumb rubber (0.05-0.7 mm) as substitutions of fine aggregates by volume and reported that the addition of 22.2% crumb rubber has no effect on j ring test value while the j ring test value is increased by with the addition of 33.3% crumb rubber [27].

Eehab Khalil et al (2015) conducted tests on SCC samples with different crumb rubber (max. 2 mm) ratios of 10%, 20%, 30% and 40% sand replacement by volume. Here the passing ability is checked by L-box test. He reported when 40% rubber content is added in SCC, passing ability by about of SCC decreased by 13.1% with respect to that of the case of the SCC with no rubber content [28].

M.M. Rahman et al (2012) investigated the Fundamental properties of rubber modified self-compacting concrete with various rubber content. By L-box test results he concluded that rubber modified SCC has a considerable lower passing ability ratio (0.28–0.4) when compared to normal SCC and passing ability is not enhancing with the increase of superplasticizer [34].

N. Ganesan et al (2012) replaced sand by shredded rubber of 15% and 20% and volume fraction of steel fibres. According to his L-box test data it is clear that there is not much of difference between the passing ability of conventional SCC and rubberized SCC with viscosity modifying agent [36].

3.3. Compressive strength

Out of all the properties of concrete, is the utmost important which gives an idea about all the characteristics of concrete. Generally this is calculated by casting cubes of size15 cm x 15 cm x 15 cm and compressive strength testing machine.

M.C. Bignozzi et al (2006) used 0, 22.2 and 33.3 % grinded crumb rubber (0.05-0.7 mm) as substitutions of fine aggregates by volume and concluded that compressive strength decreases with increment of rubber phase on SCC mixes [27].

Eehab Khalil et al (2015) prepared SCC samples with different crumb rubber (max. 2 mm) ratios of 10%, 20%, 30% and 40% sand replacement by volume and concluded that a reduction of about40% on compressive strength observed from 0% to 40% rubber content sand replacement [28].

Ilker Bekir Topçu et al (2009) replaced aggregateswith rubber contents of 60, 120 and 180 kg/m^3 in SCC by weight. The result of the test conducted by them indicated that compressive strength of rubberized decreases with increment of rubber aggregates [29].

Tayfun Uygunogluet al (2010) prepared SCC by replacing sand with different scrap rubber (1-4 mm) ratios 0%, 10%,20%, 30%, 40% and 50% (by weight of sand) with various W/p ratio. He concluded use of rubber tire aggregate reduces the 7 days compressive strength by 40 to 64% and the 28 days compressive strength by 48 to 58% [30].

Mehmet Gesoglu et al (2011) used four designated crumb rubber contents of 0%, 5%, 15%, and 25% by volume of fine aggregate to replace the fine aggregates i.e. sand. It is evident from his test data that there is an ample decrement in the compressive strength of concretes with increment of rubber aggregate content, regardless of the age of sample [32].

Khalid B. Najim et al (2012) investigated the property of crumb rubber modified self-compacting concrete utilizing crumb rubber (2–6 mm) from scrap tires as a partial replacement for coarse aggregate, fine aggregate, and combined coarse and fine aggregate by 5, 10, and 15 weight % proportions. He concluded that The FCR (Combined fine and crumb rubber) replacement offered the best results for compressive strength [42].

E. Güneyisiet al (2016) utilized crumb rubber and tire chips, to partially replace the fine and coarse aggregate on SCC mixes at various level. The compressive strength is obtained during this study ranging between31.0 and 62.8 MPa. He concluded incorporation of rubber tyre in SCC could be a reason of decrement of compressive strength but compressive strength more than 30 MPa could be achieved in the self-compacting concrete including 25% crumb rubber or tire chips [38].

Mohamed K. Ismail et al (2015) prepared SCC samples with different percentages of crumb rubber (0-40% by volume of sand) and different types of cementitious materials. He came to a decision that these percentages of crumb rubbers decreases compressive strength by around 59.25%. Whereas by using Metakaolin can be suggestively increase the compressive strength of rubberized self-compacting concrete mixtures by 49.2 % [33].

M.M. Rahman et al (2012) and **Wang Her Yung et al(2012)** also concluded from their study that compressive strength of SCC is gradually decreased for rubber utilization [34, 35].

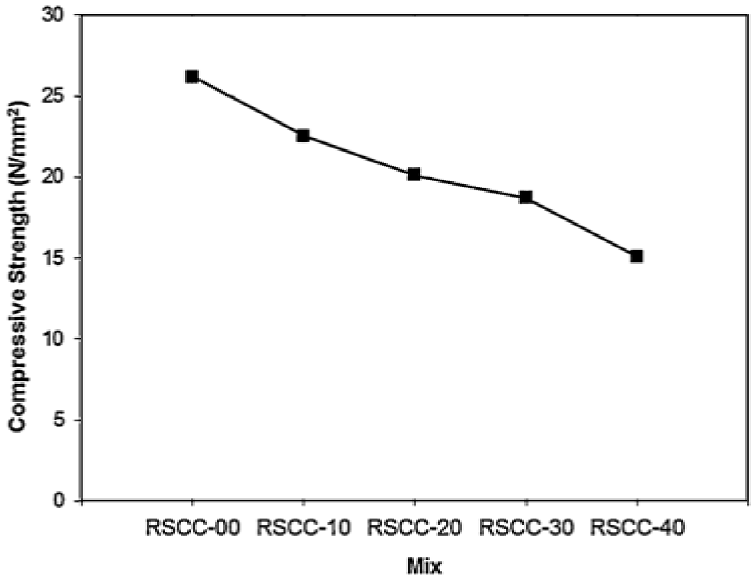

Fig2: Compressive strength for various percentage of rubber content [28].

Table 1: Flowability and passing ability of the rubberized self-compacting concrete

Author (year)	Rubber replacement	Flowability	Passing ability
M.C. Bignozzi et al (2006) [27]	0, 22.2 and 33.3 % grinded crumb rubber (0.05-0.7 mm) substitutions of fine aggregates by volume.	Addition of 33.3% crumb rubber increased 70 cmslump dia.whereas use off 22.2% has no effect.	Addition of 33.3% crumb rubber increased passing ability whereas use off 22.2% has no effect.
Eehab Khalil et al (2015)[28]	Crumb rubber (max. 2 mm) ratios of 10%, 20%, 30% and 40% as a replacement sand by volume.	40% rubber content in SCC decreased flowabilty about 75 mm with respect to that of the case of the SCC with no rubber content.	40% rubber content in SCC decreased passing ability by 13.1% with respect to that of the case of the SCC with no rubber content.
Ilker Bekir Topçu et al (2009)[29]	Rubber contents of 60, 120 and 180 kg/m^3 replaced with aggregates in SCC by weight.	Slightly increased with the increase of rubber contents. The flow diameter are between 69 and 80 cm.	
N. Ganesan et al (2012)[36]	Replaced sand by shredded rubber of 15% and 20%.	Decreasing with increasing amount of rubber content.	No significant difference between the conventional SCC and rubberized SCC with viscosity modifying agent.
E. Güneyisi et al (2016)[38]	Crumb rubber and tire chips, to partially replace the fine and coarse aggregate on SCC mixes at various level.	Slump flow diameter of SCC with crumb rubber (i.e.680-750 mm) is higher than of tire chips (i.e. 560-710 mm).	
Tayfun Uygunoglu et al (2010)[30]	Sand replaced with different scrap rubber (1-4 mm) ratios 0%, 10%,20%, 30%, 40% and 50% (by weight of sand) using on various w/p ratios.	Decreased with the increment of rubber content. Flow dia. Is 110 -230 mm in SCC mixture using a rubber content of 50% depending on various w/p ratios.	

3.4. Flexural Strength

Eehab Khalil et al (2015) prepared SCC samples with different crumb rubber (max. 2 mm) ratios of 10%, 20%, 30% and 40% sand replacement by volume and concluded that the flexural strength decreasing gradually with the increase of rubber content and a reduction of about 29% on flexural strength was observed from 0% to 40% rubber content [28].

Tayfun Uygunoglu et al (2010) prepared SCC by replacing sand with different scrap rubber (1-4 mm) ratios 0%, 10%,20%, 30%, 40% and 50% (by weight of sand) with various W/p ratio. He reported that flexural strength reduced with increasing rubber content and indicated a gradual reduction from 55% to 31% depending on w/p ratio in the flexural strength [30].

Khalid B. Najim et al (2012)) investigated the property of crumb rubber modified self-compacting concrete utilizing crumb rubber (2–6 mm) from scrap tires as a partial replacement for coarse aggregate, fine aggregate, and combined coarse and fine aggregate by 5, 10, and 15 weight % proportions. According to his test data flexural strength reduces by fewer than 11% for all types of 5 wt% rubber content replacement, however at 15 wt% rubber content replacement the reduction is 39% [42].

N. Ganesan et al (2012) replaced sand by shredded rubber content of 15% and 20% and volume fraction of steel fibres. He reported that for adding 15% and 20% rubber content in SCC specimens, the static flexural strength improved by 15% and 9% respectively in comparison to conventional SCC specimens [36].

Mohamed K. Ismail et al (2015) reported in his study the addition of 20% and 40% CR in SCC mixes decreased the 28-day Flexural strength by 15.54 and 35% respectively without any admixture. Whereas by using Metakaolin can be significantly increase the flexural strength of rubberized self-compacting concrete mixtures. He shows that rubberized self-compacting concrete mixtures having 30% crumb rubber has higher values for conventional rubberized self-compacting concrete with 30% crumb rubber [33].

3.5. Splitting Tensile Strength

Eehab Khalil et al (2015) prepared SCC samples with different crumb rubber (max. 2 mm) ratios of 10%, 20%, 30% and 40% sand replacement by volume and concluded that a gradual reduction in splitting tensile strength observed from 0% to 40% rubber content sand replacement [28].

Khalid B. Najim et al (2012)investigated the property of crumb rubber modified self-compacting concrete utilizing crumb rubber (2–6 mm) from scrap tires as a partial replacement for coarse aggregate, fine aggregate, and combined coarse and fine aggregate by 5, 10, and 15 weight % proportions. From his test results it is crystal clear that the splitting tensile strength of rubberized self-compacting concrete is decreasing with the increment of rubber content of various particle sizes. It has been noted that the 5% coarse rubber replacement gives higher splitting tensile strength than 5 % fine rubber or 5% combined rubber particles whereas for the case of 10% and 15% rubber replacement fine rubber gives better result than other two rubber particle sizes [42].

Mohamed K. Ismail et al (2015) observed in his study that the splitting tensile strength decreases as a crumb rubber increases. It is reported increasing the percentage of rubber particles from 0% to 40% reduces the 28-day splitting tensile strength about 52.41%. Though addition of 20% metakaolin increased the 28-day splitting tensile strength of rubberized self-compacting concrete about 17% [33].

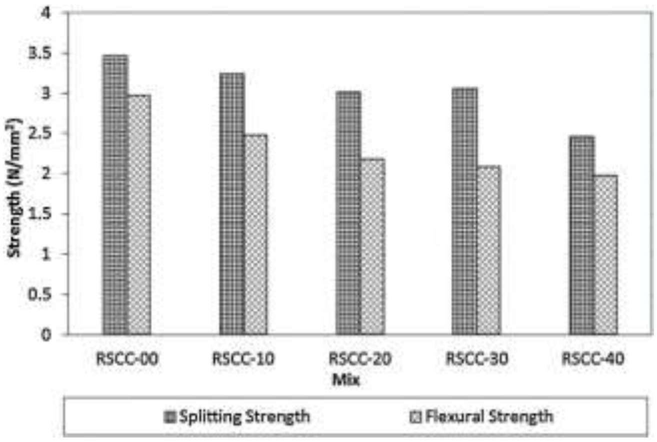

Fig3. Splitting and flexural strength for all mixes [28]

3.6. Dynamic Elasticity of Modulus

There is a general but non-defined correlation between compressive strength and elasticity of modulus in concrete. Dynamic elasticity of modulus can be determined using Ultrasonic equipment i.e. Non-destructive test.

M.C. Bignozzi et al (2006) used 0, 22.2 and 33.3 % grinded crumb rubber (0.05-0.7 mm) as substitutions of fine aggregates by volume and reported that dynamic elasticity of modulus is decreased with the increment of rubber content[27].

Khalid B. Najim et al (2012) investigated the property of crumb rubber modified self-compacting concrete utilizing crumb rubber (2–6 mm) from scrap tires as a partial replacement for coarse aggregate, fine aggregate, and combined coarse and fine aggregate by 5, 10, and 15 weight % proportions. He concluded Dynamic modulus of elasticity decrease systematically with increment of rubber content [42].

M.M. Rahman et al (2012) investigated the Fundamental properties of self-compacting concrete adding various rubber content. According his data the concluded Dynamic modulus of elasticity of rubberized SCC is lower than SCC with no rubber content[34].

Mohamed K. Ismail et al (2015) prepared SCC samples with different percentages of crumb rubber (0-40% by volume of sand) and different types of cementitious materials. He came to a decision that the elasticity of modulus decreased by 3.7% at 5% crumb rubber, while at 40% crumb rubber addition causes the reduction in elasticity of modulus is 46.1% compared to the control mixture (0% crumb rubber [33].

3.7. Water Absorption

Water absorption of concrete related to the durability of concrete. So it is a significant property of concrete.

M.C. Bignozzi et al (2006) used 0, 22.2 and 33.3 % grinded crumb rubber (0.05-0.7 mm) as substitutions of fine aggregates by volume and reported that water absorption percentage is increased about 0.8 % with the increment of 33.3% rubber content [27].

Tayfun Uygunoglu et al (2010) prepared SCC by replacing sand with different scrap rubber (1-4 mm) ratios 0%, 10%,20%, 30%, 40% and 50% (by weight of sand) with various W/p ratio. According to his test results SCC without rubber content absorb less water than the rubberized SCC. He reported at w/p ratio of 0.40–0.51, the absorption of the SCC without rubber aggregate varies between about 7 to 11%, the water absorption values of rubberized SCC comprising 50% rubber ranges from 12 to18% [30].

Mehmet Gesoglu et al (2011) used four designated crumb rubber contents of 0%, 5%, 15%, and 25% by volume of fine aggregate to replace the fine aggregates i.e. sand. He observed use of crumb rubber in SCC made it more absorbent with an growing rate of crumb rubber content. His results shows that the water absorption of the SCC ranges between 2.73% to 4.25% and between 2.56% to 4.03% at 28 and 90 days depending on the contents of crumb rubber aggregate and fly ash respectively [32].

N. Ganesan et al (2012) replaced sand by shredded rubber of 15% and 20%. His test result shows the water absorption of rubberized self-compacting concrete if 50% of conventional SCC [36].

Malek Jedidi et al (2014) observed that the water absorption of rubberized SCC grows as the percentage of crumb rubber content increases [40].

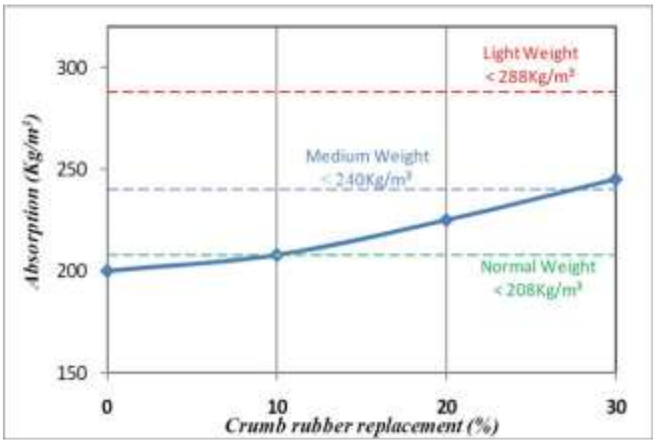

Fig 4. Effect of crumb rubber on water absorption [**40**]

3.8. Shrinkage

Shrinkage is also another important property of hardened concrete. Most of the cracks in concreteare form due toshrinkage. Shrinkage in concrete may classified as Plastic Shrinkage, drying shrinkage, carbonation Shrinkage etc.

Tayfun Uygunoglu et al (2010)prepared SCC by replacing sand with different scrap rubber (1-4 mm) ratios 0%, 10%,20%, 30%, 40% and 50% (by weight of sand) with various W/p ratio. He conclude that shrinkage improved with an increase in rubber aggregate content in SCC. He reported the maximum shrinkage can be obtained with maximum w/p ratio whereas the lowest shrinkage can be achieved in rubberized SCC with the minimum w/p ratio [30].

Wang Her Yung et al (2010)concluded that the shrinkage of SCC would become higher as more waste tire rubber powder is added [35].

4. CONCLUSION

Utilization of waste rubber tires in self-compacting concrete is reviewed in this paper. A brief report on various properties of self-compacting concrete using rubber aggregates are reviewed and compared. Based on this comparison and review these following conclusion can be drawn.

- The waste rubber tire aggregates can be used in SCC as partial replacement of both coarse aggregates and fine aggregates.
- Various properties of waste rubber tires like specific gravity, water absorption etc. indicated that rubber aggregates helps in the production of lightweight SCC. For the ductility property of rubber the strain capacity of SCC is also increases.
- From the review it can be conclude that the flowability of SCC is decreasing with increment of rubber aggregate content. To achieve good flowability slightly higher amount of superplasticizer is required.
- The passing ability of SCC is also decreased with the addition of rubber tire aggregate but it can be maintained by using viscosity modifying agents.
- Compressive strength experiences significant negative effect when rubber tire aggregates are utilized in SCC. However the compressive strength of rubberized SCC can be increased by introducing metakaolin or steel fibers in the mix.
- Though the other mechanical properties (i.e. flexural strength, splitting tensile strength, dynamic modulus of elasticity etc.) gradually reduced with the increase of rubber content, still performance of rubberized SCC is better than ordinary SCC.
- Water absorption of SCC is significantly increased using the waste tire aggregates.
- It is evident from the reviews that shrinkage of SCC improved with increment of tire aggregate content.

So from the review it can be conclude that the waste rubber aggregate confidently used in self-compacting concrete and by doing this sustainability can be achieved in construction industry.

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BIOGRAPHIES

Sukamal Kanta Ghosh, M. Tech Student, School of Civil Engineering. KIIT University, Bhubaneswar, Odisha-7 5 1 0 2 4, India Specialization: Construction Engineering and Management. Thrust area: Concrete Technology, Self-compacting concrete, Pervious concrete.

D. K. Bera, Asst. Professor in School of Civil Engineering, KIIT University, Bhubaneswar, Odisha - 7 5 1 0 2 4. Designation: Asst. Prof. & Assoc. Dean T & P. Specialization: Construction Engineering and Management. Thrust area: Concrete Technology, Nano Technology, Construction management.