UTILISATION OF WASTE TYRE RUBBER IN CONCRETE AND POSSIBLITY OF INCLUDING THEM AS AGGREGATES IN RIGID PAVEMENT – A LITERATURE REVIEW

Asheeka A[1], Indhu P[1], Balakumar P[2]

[1]Third year B.E., Department of Civil Engineering, PSG Institute of Technology and Applied Research, Coimbatore, India.

[2] Assistant Professor, Department of Civil Engineering, PSG Institute of Technology and Applied Research, Coimbatore, India.

ABSTRACT: The volume of polymeric tyre rubber wastes is increasing at a faster rate. An estimated 1000 million tyres reach the end of their useful lives every year all over the world and 5000 millions more are expected to be discarded in a regular basis by the year 2030. Up to now a small part is recycled and millions of tyres are just stockpiled, landfilled or buried. This paper reviews research published on the performance of concrete containing tyre rubber. Further more it explores the possibility of using the tyre rubber wastes as aggregates in rigid pavement.

Keywords –Waste Tyre Rubber Tyre Wast, rubberized concrete –fresh and hardened properties, rigid pavements, durability, fatigue, toughness, Crumb Rubber Concrete

1. INTRODUCTION:

There is an increasing concern over the high levels of waste generation that are impossible to split into original components, such as rubber waste derived from end-of-life tyres. LMC Automotive predicts that by 2024 the vehicle fleet will have grown by 25% worldwide and is estimated that around 355 million tyres are produced in the EU per annum [1,2]. Unlike other products such as paper or glass, the use of recycled material in the manufacture of new tyres is impractical, among other aspects due to strict safety requirements [3], therefore, the increasing demand of new tyres brings about more raw materials consumption. Europe is currently facing a similar challenge of reducing the consumption of raw materials, such as natural rubber. In 2008, the European Commission approved The Raw Materials Initiative, establishing a strategy to address the problem of access to raw materials, based on a fair and sustainable supply of ‘‘secondary raw materials” obtained through recycling [4].

Waste tyre rubber has been remarked as a toxic and hazardous waste [5]. Recovery and disposal of end-of-life tyres is recognized as ‘‘black pollution” [6], as this waste has a strong impact over environment. A large part of discarded tyres ends up stockpiled in waste disposal sites without having been subjected to any specific treatment prior to storage. The growing number of these waste disposal sites poses phytosanitary risk, increasing the chances of fires and segregation of the space they occupy in relation to their environment. The handling and storage of end-of-life tyres is a major threat to public health and aesthetic implications. The increase in per capita income favours the expansion of automobile for personal use as well as public investments in road systems, which encourages the purchase of new vehicles and consequently the increasing of abandoned tyres [7]. Tyre landfilling is responsible for possessing a serious ecological threat. Mainly waste tyres disposal areas contribute to the reduction of biodiversity also the tyres hold toxic and soluble components [8]. Although waste tyres are difficult to ignite, this risk is always present. Once tyres start to burn due to accidental causes high temperature is induced and toxic fumes are generated [9] besides the high temperature causes tyres to melt, thus producing oil that will contaminate soil and water.

2. WASTE TYRE RUBBER IN CONSTRUCTION:

Classification of scrap rubber tyre in most of the researches performed, usually three broad categories of discarded tyre rubber have been considered such as chipped, crumb and ground rubber: (a) Shredded or chipped rubber to replace the gravel. To produce this rubber, it is needed to shred the tyre in two stages. By the end of stage one, the rubber has length of 300–430 mm long and width of 100–230 mm wide. In the second stage its dimension changes to 100–150 mm by cutting. If shredding is further continued, particles of about with 13–76 mm in dimensions are produced and are called ‘‘shredded particles”. (b) Crumb rubber that replaces sand, is manufactured by special mills in which big rubbers change into smaller torn particles. In this procedure, different sizes of rubber particles may be produced depending on the kind of mills used and the temperature generated. In a simple method, particles are made with a high irregularity in the range of 0.425–4.75 mm. (c) Ground rubber that may replace cement is dependent upon the equipment for size reduction.

3. FRESH PROPERTIES OF CONCRETE WITH WASTE TYRE RUBBER - WORKABILITY:

Cairns et al. [10] used long and angular coarse rubber aggregates with a maximum size of 20 mm obtaining concretes with an acceptable workability for low rubber content. These authors reported a reduction in the workability for higher rubber content, being that a rubber content of 50% lead to a zero slump value. Other authors [11] studied concretes containing silica fume, crumb rubber and tyre chips reporting a decrease in slump with increasing rubber content, being that a 50% rubber content leads to mixtures without any workability. The results obtained by those authors show that reducing W/C is associated to a decrease in the slump values and that the silica fume worsens the workability performance. Albano et al. [12] replace fine aggregates by 5% and 10% of scrap rubber waste (particle sizes of 0.29 mm and 0.59 mm) reporting a decreased of 88% in concrete slump. Bignozzi and Sandrolini [13] used scrap-tyre (0.5–2 mm) and crumb-tyre (0.05–0.7 mm) to replace 22.2% and 33.3% of fine aggregates in self-compacting concretes referring that the introduction of the rubber particles does not influence the workability in a significant way if the superplasticizer also increases. Skripkiunas et al. [14] used crumbed rubber to replace 23 kg of fine aggregates in concretes with 0.6% of a policarboxile superplasticizer by cement mass obtaining the same workability of the reference concrete. Other authors [15] used crumb rubber tyres (0.075–4.75 mm) in the concrete to replace sand in various percentages (20%, 40%, 60% and 100%). These authors stated that increasing rubber waste content decreases the concrete slump. Freitas et al. [16] used scrap-tyre (0.15–4.8 mm) in the replacement of sand reporting a slump decrease along with the increase of scrap-tyre content. However, these authors used 1% by cement mass of an unknown plasticizer in the mixtures with tyre wastes, so the workability reduction is probably related to the low performance of the plasticizer. Topçu and Bilir [17] studied the influence of rubber waste with a maximum dimension of 4 mm in self-compacting concretes noticing that rubber replacing sand increase concrete workability which is due to the presence of viscosity agents even to a volume of 180 kg/m3. Aiello and Leuzzi [18] used tyre shreds (Fig. 1) to replace fine and coarse aggregates (10 mm–25 mm) with 1% by cement mass of a plasticizer observing increase workability with tyre shreds content. Guneyisi [19] used crumb rubber waste to replace sand in self-compacting concretes in different superplasticizer with different amounts. This author noticed that the mixture with 25% of rubber waste although containing 4% by cement mass of the superplasticizer did not achieved the target slump flow of 750 mm ± 50 mm. He also reported that adding fly ash helps to lower the amount of superplasticizer in the mixtures with high rubber waste content. Although the majority of investigations show that rubber aggregates lead to a decrease in concrete workability some authors reported the no workability loss and others even observed the opposite behavior. This means that workability is very dependent on the characteristics of the rubber aggregates. Future investigations should study what rubber wastes could be used to produce self-compacting concretes.

Fig. 1 *Rubber particles: (above) as they come after the shredding process; (below) during the mixture of concrete [18].*

4. **HARDENED PROPERTIES OF CONCRETE WITH WASTE TYRE RUBBER** :

4.1 Compressive strength:

Guneyisi et al. [11] mentioned that the strength of concretes containing silica fume, crumb rubber and tyre chips decreases with rubber content. These authors suggest that it is possible to produce a 40 MPa concrete replacing a volume of 15% of aggregates by rubber waste. Ghaly and Cahill [20] studied the use of different percentage of rubber in concrete (5%, 10%, and 15%) by volume also noticing that as rubber content increase leads to a reduction of compressive strength. Valadares [21] studied the performance of concretes with the same volume replacement of rubber wastes confirming the decrease of compressive strength. A waste rubber volume of 15% leads to a 50% compressive strength decrease. These authors mentioned that the rubber waste with low dimensions leads to lower strength loss and also that the rubber production (mechanical grinding or cryogenic process) does not influence the compressive strength. Freitas el al. [16] mentioned a 48.3% decrease in compressive strength for concretes with a waste rubber volume of 15%. Ganjian et al. [22] also confirmed the decrease in compressive strength for increase rubber content. However, these authors obtained a slight increase in compressive strength when 5% of chipped rubber replaced the coarse aggregates probably due to a better grading of the mixture. This finding had already caught the attention of other authors [20,24]. Snelson et al. [25] used concretes with shredded tyre chips (15–20 mm) for aggregate replacement in several percentages (2.5%, 5% and 10%) reporting a loss in compressive strength. The results show that the rubber mixtures also containing pulverised fuel ash as partial cement replacement presented major compressive strength loss.

This means that the low adhesion between the cement paste and the rubber waste becomes even lower if admixtures with low pozzolanic activity are used. Aiello and Leuzzi [18] used tyre shreds to replace fine and coarse aggregates concluding that the size of the rubber particles have a major influence on the compressive strength. When coarse aggregates are replaced by the tyre particles the compressive strength loss is much more profound when compared to the compressive strength loss of concretes in which fine aggregates were replaced by rubber particles. The results contradict the ones presented by Valadares [21] and that may be related to the origin of the wastes used in each case (car, truck or motorcycle) being that different origin may possess different chemical compositions leading to different adhesion between the cement paste and the rubber waste. Vieira et al. [26] studied three types of rubber waste (Fig. 2) and three volume percentages (2.5%; 5% and 7.5%) reporting that the best mechanical performance was obtained using just 2.5% of the tyre rubber with 2.4 mm. Several authors mentioned the use of pretreatments of rubber waste to increase the adhesion between the cement paste such as the use of a 10% NaOH saturated solution to wash the rubber surface during 20 min [27,28].

Fig. 2. Size of tire rubber [26]].

Raghavan et al. [29] confirms that the immersion of rubber in NaOH aqueous solution could improve the adhesion leading to a high strength performance of concrete rubber composites. The NaOH removes zinc stearate from the rubber surface, an additive responsible for the poor adhesion characteristics, enhancing the surface homogeneity [30]. Segre and Joekes [31] mention several pretreatments to improve that the adhesion of rubber particles like acid etching, plasma and the use of coupling agents. Cairns et al. [10] used rubber aggregates coated with a thin layer of cement paste. Albano et al. [12] study concrete composites containing scrap rubber previously treated with NaOH and silane in order to enhance the adhesion between the rubber and the cement paste without noticing significant changes, when compared to the untreated rubber composites. Oiknomou et al. [32] mentioned that the use of SBR latex enhances the adherence between the rubber waste and the cement paste. Chou et al. [33] suggest the pretreatment of crumb rubber with organic sulphur stating it can modify the rubber surface properties increasing the adhesion between the waste and the cement paste. Investigations about rubber waste concrete show a compressive strength loss with waste content increase. This behaviour is related to the low compressive strength of rubber aggregates and to the low adhesion between these wastes and the cement paste. Several treatments reveal interesting results in order to overcome this disadvantage. Further investigations are needed on this subject, especially to comprehend if different kinds of rubber behave in a similar manner to the same treatment.

4.2. Tensile strength:

Guneyisi et al. [11] analyzed the tensile strength of concretes containing silica fume, crumb rubber and tyre chips referring a decrease in tensile strength according to the rubber content also that the presence of silica fume is beneficial because it is responsible for a higher filler effect. The results also confirm that the decrease of tensile strength reduction is less influenced by the rubber content than for the compressive strength reduction. This tendency was also observed by Pierce and Williams [34] (Fig.3). This result appears to be due to the fact that rubber particles prevent crack opening

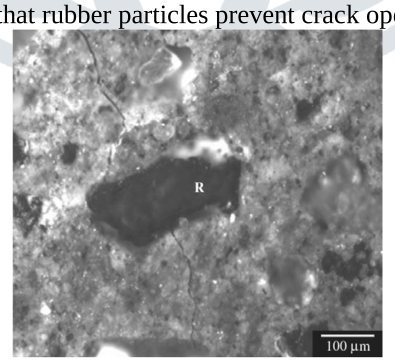

Fig. 3. *Cracking bridging effect of rubber particles* [34]

Valadares [21] obtained a higher tensile strength for concretes with rubber waste particles with a higher dimension which agrees with the previous finding. Ganjian et al. [22] mentioned the opposite behaviour reporting that the tensile strength of concrete with chipped rubber replacement for aggregates is considerably lower than for concrete containing powdered rubber. In the first case a reduction between 30% and 60% takes place for a replacement level of 5–10%, as for the latter case the reduction is between 15% and 30%. This behaviour maybe related to the very low adhesion between the chipped rubber and the cement paste. One reason for this is the fact that chipped rubber was prepared in laboratory with the help of a scissor a procedure quite different from the rubber waste particles shredded by a grinding process which favors a harsh surface. According to Aiello and Leuzzi [18] when tyre shreds are used to replace fine aggregates a high tensile (flexural) strength is obtained. A replacement of the volume of fine aggregates (50% or 75%) leads to a strength reduction of only 5.8% and 7.30%. But if the same percentages were used to replace coarse aggregates a 28.2% strength reduction will take place. The tensile strength of rubber waste concrete is influenced by the characteristics of the rubber aggregate. Some are associated with a tensile strength loss but others present a high tensile strength. Future investigation should focus on the characteristics of the rubber aggregates that enhance tensile strength.

4.3. Toughness:

Concrete composites containing tyre rubber waste are known for their high toughness [35], having a high energy absorption capacity. The ASTMC1018-97 [36] defines several toughness indexes (I5, I10 and I20) as the area under load–deflection curve of a flexural specimen for different times of deflection after crack initiation related to area under the same curve up to the crack initiation. Some authors [37] report a 63.2% increase in the damping ratio (self capacity to decrease the amplitude of free vibrations) for concrete containing 20% rubber particles. Other authors [38,39] confirmed the high damping potential of rubber waste concrete. They mentioned that concrete with ground rubber shows a 75.3% increase in the damping ratio and a 144% for crushed rubber concrete.Fioriti et al. [40] mentioned that concrete paving blocks containing 8% of tyre rubber waste (have a resistant impact of almost 300% when compared to the reference concrete. Ling et al. [41] also studied the performance of concrete paving blocks with crumb rubber reporting a high toughness resistance due to the energy absorbing capacity. These means that tyre waste concrete maybe specially recommended for concrete structures located in areas of severe earthquake risk and also for the production of railway sleepers.

4.4. Modulus of elasticity:

Since the concrete with rubber waste has low compressive strength and a correlation exists between compressive strength and the modulus of elasticity it is expected they also possess lower modulus of elasticity. However, Skripkiunas et al. [14] compared concretes with similar compressive strength (a reference one and another with 3.3% of crumb rubber) obtaining different static modulus of elasticity, 29.6 GPa versus 33.2 GPa for the reference concrete just 11% higher. The explanation for this behaviour is related to the low modulus of elasticity of rubber waste [42]. Other authors [43] report a decrease in the modulus of elasticity of 40% when the same percentage reduction takes place for compressive strength. Khaloo et al. [44] confirmed that the inclusion of tyre rubber particles leads to a high ductility concrete. Zheng et al. [38,39] mentioned that the crumb rubber (80% <2.62 mm) has a lower influence in the modulus of elasticity than the crushed rubber (15–40 mm). Turatsinze and Garros [45] refer that the modulus of elasticity of self-compacting concrete is increased with rubber (4–10 mm) waste content. These authors also mentioned the risk of severe segregation with a high concentration of rubber waste at the top of the specimens which implies the needed for a proper combination between a viscosity agent and air-entraining agent to avoid segregation. Other authors [46] studied the modulus of elasticity of concrete columns with two different sizes of crumb rubber (0.6 and 1 mm) reporting an increase in the ductility performance up to 90%. Those authors mentioned that crumb rubber concrete columns can undergo twice the lateral deformation before failure compared to the reference concrete columns. Mohammed [47] confirmed that concrete slabs containing crumb rubber with a finesses modulus of 2.36 shows a higher ductility behavior which fulfil the ductility requirements of Eurocode 4 [48].

4.5. Durability:

Since rubber waste concrete has lower compressive strength and lower tensile strength than reference concrete it is expected that is behaviour under fast mechanical degradation actions could also be lower. Sukontasukkul and Chaikaew [49] mentioned that crumb concrete blocks show less abrasion resistance and also that increasing the crumb rubber content leads to a reduction in the abrasion resistance. This result is confirmed by other authors [41]. Freitas e al. [16] studied the abrasion resistance by immersion of rubber waste concrete reporting a lower degradation than the reference concrete when only 5% rubber per mass is used to replace the coarse aggregate. This result is quite interesting since the rubber addition leads to a 30% compressive strength decrease. However, since the tensile strength has been reduced only 11% this helps to understand the high abrasion resistance. The authors used this mixture in the rehabilitation of a hydroelectric power plant. Topeu and Demir [50] mentioned that a high volume replacement of sand by rubber waste (1–4 mm) has lower durability performance assessed by freeze–thaw exposure, seawater immersion and high temperature cycles. According to them the use of a 10% replacement is feasible for regions without harsh environmental conditions. The fact that these authors used a Portland cement II/B 32.5 which has a very low compressive strength one may be able to explain these results. Ganjian et al. [22] studied the durability of concrete containing scrap-tyre wastes assessed by water absorption and water permeability revealing that a percentage replacement of just 5% is associated with a more permeable concrete (36% increase) but not a more porous one. Increasing the rubber percentage replacement to 10% doubles the concrete water permeability which means this kind of concrete cannot be used for applications where water pressure is present like underwater columns. Ling et al. [51] tested 348 rubber waste paving blocks reporting that an increase in the rubber waste decreases the abrasion resistance. Thus the recommendation that a 20 vol.% replacement should not be exceeded. The durability of rubber waste concrete is a subject that needs further investigations. How different wastes influence durability parameters and most importantly how waste treatment can enhance the concrete durability are questions that must be addressed.

5.PATHOLOGIES OF RIGID CONCRETE SURFACES:

Concrete pavements posses considerable advantages compared to flexible pavements, like longer useful life with a high service rate, higher resistance to adverse climate conditions, lower requirements of supporting structure and shorter execution and maintenance delays. Rigid Pavements have an important drawback due to its high initial cost.Finding new materials which are less expensive and highly durable is crucial for building safer, less expensive and more durable roads. The addition of rubber waste to bituminous mixtures to be used in flexible surfaces has been extensively explored, although its inclusion in rigid surfaces still requires a more in-depth study.

6.1. WASTE TYRE RUBBER CONCRETE FOR RIGID ROAD PAVEMENTS:

Due to their tensile properties, rubber particles block the expansion of micro-cracks and delay the occurrence of new cracks under cyclic loading. This effect enhances fatigue life of the material [52] and is a key aspect in the evaluation of its performance under cyclical efforts similar to traffic loads. Traditional tests designed to evaluate the fatigue resistance of plain concrete seem generally applicable to rubber concrete. However, the degree of deformation suffered by the material and the delay in the appearance of microcracks is not evaluated in conventional tests. Rosalía et al [53] investigated the suitability of using discarded waste tyre rubber particles in concrete rigid road pavements. Rubber particle size was optimized and proportioned to improve the material performance. A tests program was carried out to know the effect of rubber size and rubber content on mechanical properties of concrete pavements. Mixtures with rubber particles of variable sizes (1–4, 10 and 16 mm) added in different proportions (10, 20 and 30%) are considered. A novel test to evaluate deformation (in terms of transversal micro-cracks) suffered by the material under cyclical efforts similar to traffic loads is proposed. The results exhibited that there exists an optimal combination of size and proportion of rubber particles that improves the performance of the material under cyclic load stresses, which makes the material suitable for the construction of rigid concrete pavements and was concluded that rubber percentages above 20% are excluded, as they considerably reduce the mechanical properties of the concrete.

6.2. PERFORMANCE OF CRUMB RUBBER CONCRETE (CRC) RIGID PAVEMENTS:

Iman Mohammadi et al [54] dealt with the shrinkage properties of Crumb rubberised concrete pavement. Arrays of concrete samples were prepared with different water–cement ratios and rubber content. The experimental results showed that the introduction of rubber into concrete mixes results in the control of shrinkage cracks if the optimised content of rubber is selected. Accordingly, the optimised rubber content was determined based on the mix characteristics, mechanical properties and the results of plastic and drying shrinkage tests.. The results were promising that the most reliable performance results can beachieved for samples prepared with the rubber contents of 20% and 25% of fine aggregates, and water–cement ratios of 0.45 and 0.40, respectively. Bashar S. Mohammed et al., [55] developed high volume fly ash (HVFA) RCC pavement by partially replacing 50% cement by volume with fly ash where Crumb rubber was used as a partial replacement to fine aggregate in HVFA RCC pavement at 0%, 10%, 20%, and 30% replacement by volume. Nano silica was added to improve early strength development and mitigate the loss of strength due to the incorporation of crumb rubber..Combined UPVRN (SonReb) models for predicting the 28 days strength of HVFA RCC pavement based on NDT Tests developed using multivariable regression (double power, bilinear, and double exponential models).

7. DISCUSSIONS:

The effective handling of hard-to-dispose waste, such as tyre rubber, resulting from end-of-life tyres poses a environmental, technical and regulatory challenge, and its inclusion in concrete offers a viable alternative to reduce the volume of this waste that is being stored. Inclusion of waste tyre rubber in concrete by partially replacing coarse and fine aggregates. From the studies it is able to note that the compressive strength of rubberized concrete slightly gets reduced. Consequenty, Modulus of elasticity also gets reduced. To compensate this decrease in strength, researches should be carried out by incorporating fillers in rubberized concrete. Yet, the toughness of rubberized concrete is more due to its energy absorption capacity. This property may be utilized by appling waste tyre rubber technology in construction of rigid pavements. By arriving at the optimum size and mix proportion, the rubberized concrete performs better under fatigue. So more explorations are to be done for utilizing the waste tyre rubber in shredded or crumb form in rigid pavements.

8. CONCLUSION:

Further investigations are to be made to compensate the marginal decrease in the rubberized concrete strength. Future research should focus on the inclusion of fine or coarse rubber tyre waste aggregates rigid pavements. Also optimum mix proportion of the rubberized concrete is to obtained for the easier pratical purposes.

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