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Application of waste tire rubber aggregate in porous concrete

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Abstract. This study aimed to categorize pervious rubberized concrete into fresh and hardened concrete analyzing its durability, permeability and strength. During the globalization of modern life, growing population and industry rate have signified a sustainable approach to all aspects of modern life. In recent years, pervious concrete (porous concrete) has significantly substituted for pavements due to its mechanical and environmental properties. On the other hand, scrap rubber tire has been also contributed with several disposal challenges. Considering the huge amount of annually tire wastes tossing out, the conditions become worse. Pervious concrete (PC) gap has graded surface assisted with storm water management, recharging groundwater sources and alleviate water run-offs. The results have shown that the use of waste tires as aggregate built into pervious concrete has tremendously reduced the scrap tire wastes enhancing environmental compliance.

Keywords: pervious concrete; rubber tire; waste; sustainability; environment

1. Introduction

Concrete is the single most widely used material in the world (Shariati 2008). It is an important construction material used extensively in buildings, bridges, roads and dams (Luo *et al.* 2019, Xie *et al.* 2019). Its uses range from structural applications, to paviors, kerbs, pipes and drains (Nosrati *et al.* 2018, Sajedi and Shariati 2019, Trung *et al.* 2019). Concrete as a composite material has different range of preparation depending on its application like its usage as high strength concrete (Arabnejad Khanouki *et al.* 2011, Shariati *et al.* 2011b, Shariati *et al.* 2012a, Shariati *et al.* 2012c, Shariati *et al.* 2012d, Shariati 2013, Mohammadhassani *et al.* 2014a, Mohammadhassani *et al.* 2014b, Mohammadhassani *et al.* 2014c, Shariati 2014, Shariati *et al.* 2014a, Shariati *et al.* 2014b, Khorramian *et al.* 2015, Shariati *et al.* 2015, Khanouki *et al.* 2016, Shahabi *et al.* 2016, Shariati *et al.* 2016, Khorramian *et al.* 2017, Nguyen-Sy *et al.* 2017, Hosseinpour *et al.* 2018, Nasrollahi *et al.* 2018, Ziaei-Nia *et al.* 2018) or light weight concrete (Shariati *et al.* 2010, Hamidian *et al.* 2011, Shariati *et al.* 2011a, Shariati *et al.* 2011c, Shariati *et al.* 2012b, Shariati *et al.* 2017, Vo-Duy *et al.* 2017, Ho-Huu *et al.* 2018, Davoodnabi *et al.* 2019) which are commonly used concrete in structures. Application of this important material in structure with special characteristics is extended to some other important usage in the life like pavement and roads. Pervious concrete (no-fines concrete) is one of them (Toghroli *et al.* 2017, Li *et al.* 2019, Bahari *et al.* 2018, Bahari *et al.* 2012).

It's a mixture of hydraulic cement, smaller coarse aggregates, admixtures and water, percolated by the concrete into subbase recharging the under-ground water levels (Sinaei *et al.* 2011, Ghosh *et al.* 2015). It is partly due

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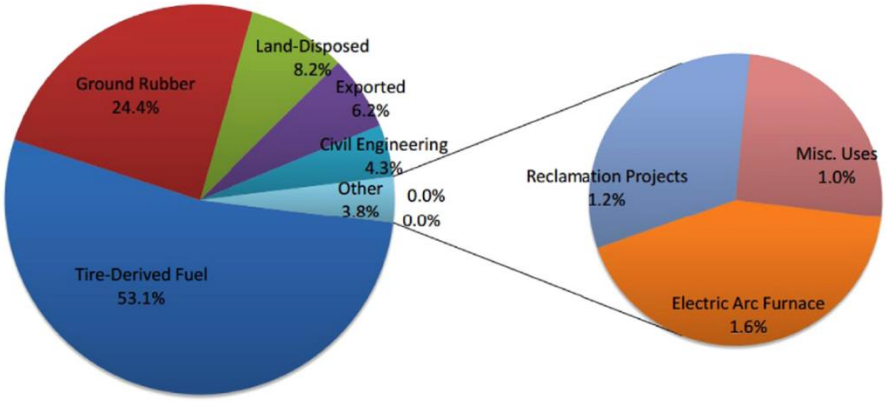

Fig. 1 Summary of US scrap market

to the impervious nature of the bituminous and concrete pavements. PC as an open-graded material has significant permeability due to the interconnected pores, ranging from 2 to 8 mm. Obtaining great amount of storm water seeping into the ground, PC has been taken in recharging groundwater and reducing storm water runoff (Talsania *et al.* 2015). Permeable concrete as PC has been applied to alleviate local flooding in urban eras providing water flowing in impermeable infrastructure (Kia *et al.* 2018). PC as porous concrete or enhanced porosity concrete is a macro-porous concrete widely applied in sustainable constructions (Neithalath *et al.* 2010). Following the "zero-waste" notion, majority of US communities have focused on urban waste-streams and recycling industry. Accordingly, contribution of waste-stream materials with storm-water facilities like PC has significantly addressed the storm water treatment and the material's sustainability (Hager 2009). A research conducted by McGrath group has shown that approximately 40 million tons of recycled aggregates are manufactured in the UK every year which is only consisted of 20% of whole aggregates market (Ganjian *et al.* 2015). In order to achieve sustainable environment and development, waste management should be planned and developed meticulously prior to every construction project (Batayneh *et al.* 2007). Waste rubber tire has been globally considered hazardous gained by automobile industries. Regarding the non-biodegradability of waste rubber tires in nature, burning down the wastes is the cheapest decomposing solution, but resulting air pollution including greenhouse gases that signify the waste rubber tires' re-application. Waste rubber is known for its noteworthy sustainability indicators such as embodied energy, material input factor, known as ecological rucksack, and carbon footprint. The value and the definition of these parameters are provided in Table 1. The reported values justify the necessity of reusing rubber instead of its disposal. Such justification is the main reason for current recycling rate of 300 million pounds of used rubber to crumb rubber annually. Because of the elasticity, lightweight, energy absorption, and heat insulating , it has been taken as a promising material in constructions (Ghosh *et al.* 2015).

The reliable performance of porous concrete as a structural component has been proved by various investigations. Also, steel-concrete composites were manufactured with lightweight and high strength concrete to evaluate the different loading and composition scenarios. Besides, applying lightweight concrete showed the outstanding results which satisfied the scholars to continue the use of this type of concrete in composite systems. Therefore, with respect to previous studies on the composite beams and floor systems, the pervious concrete could be a suitable replacement for lightweight concrete in these systems. Moreover, according to the properties of porous concrete, the hollow section thin-walled structures as steel rack systems could be reinforced with the lightweight pervious concrete (Shariati *et al.* 2010, Shariati *et al.* 2011c, Shariati *et al.* 2012b, Shariati *et al.* 2012a, Shariati *et al.* 2012f, Shariati *et al.* 2012e, Shariati 2013, Shariati *et al.* 2013, Shariati *et al.* 2014a, Shariati *et al.* 2014b, Khorramian *et al.* 2015, Shariati *et al.* 2015a, Khorramian *et al.* 2016, Shariati *et al.* 2016, Tahmasbi *et al.* 2016, Shariati *et al.* 2017b, Hosseinpour *et al.* 2018, Chen *et al.* 2019).

Hitherto various types of pervious concrete have been produced; hence, several experimental results are available which could be examined through the soft-computing, artificial intelligence algorithms, hybrid analytical solutions, or other analytical assessments. Therefore, the developed algorithms and the predicted results of pervious concrete are reliable sources for scholars or the construction industries (Sinaei *et al.* 2012, Toghroli *et al.* 2014, Khalilpasha *et al.* 2012, Sadeghi-Nik *et al.* 2012, Sadeghi-Nik *et al.* 2017 Hamdia *et al.* 2015, Mohammadhassani *et al.* 2015, Toghroli 2015, Mansouri *et al.* 2016, Safa *et al.* 2016, Thang *et al.* 2016, Toghroli *et al.* 2016, Khorami *et al.* 2017a, Tai *et al.* 2017, Sari *et al.* 2018, Sedghi *et al.* 2018, Toghroli *et al.* 2018a, Katebi *et al.* 2019, Mansouri *et al.* 2019, Shariati *et al.* 2019b, Shi *et al.* 2019b, Shariati *et al.* 2019a, Khorami *et al.* 2017b, Trung *et al.* 2019, Xu *et al.* 2019).

High-porosity is one of the major specifications of the pervious concrete. Since the thermal behavior of concrete depends on its porosity, it seems that the porous texture could be appealing to researchers who studied the thermal performance of concrete, especially at the elevated temperatures (Shahabi *et al.* 2016a, Davoodnabi *et al.* 2019).

Concerning the compressive strength range of pervious

Table 1 Sustainability indicators of rubber

Indicator	Definition	Value	Reference
Embodied Energy	The energy consumed by all of the processes associated with the production of a material from the extraction to manufacturing, transport and product delivery.	110 M Joules/kg	Kibert (2007)
Material Input Factor (Ecological Rucksack	the total mass (in kg) of m aterials removed from nature to produce a material	5 kg/kg	
Carbon Footprint	The mass of carbon dioxide released into the atmospher e due to the production of one unit mass of a matter	1.16-1.53 $kgCO_2$/kg matter	Sympath & Kennedy (2015)

concrete and its low tensile strength, using this kind of concrete is not a logical choice for cast in beams or steel tubes. However, applying the synthetic fibres or other additives could enhance the mechanical properties of pervious concrete to be used in the applications mentioned above (Arabnejad Khanouki *et al.* 2011, Shao *et al.* 2018, Sinaei *et al.* 2011, Shao *et al.* 2019, Mohammadhassani *et al.* 2014a, Mohammadhassani *et al.* 2014c, Arabnejad Khanouki *et al.* 2016a, Shah *et al.* 2016, Toghroli *et al.* 2017, Heydari and Shariati 2018, Luo *et al.* 2019, Wang *et al.* 2019, Xie *et al.* 2019, Shao and Vesel 2015, Shi *et al.* 2019a).

The word "pervious" typically refers to the porous concrete that is applied for pavement constructions. However, pervious concrete due to its high porosity and low density cannot perform like a high-performance or normal concrete. Thereby, the mechanical and chemical properties of pervious concrete could be improved not only for further studies but also for building industries (Arabnejad Khanouki *et al.* 2010, Abedini *et al.* 2017, Nosrati *et al.* 2018b, Abedini *et al.* 2019, Sajedi and Shariati 2019a). In addition, various methods are currently used to evaluate the structural health monitoring; hence, constructions produced from pervious concrete could be a proper option for the health monitoring process (Hamidian *et al.* 2012).

Also, the pervious concrete could be employed in steel-concrete composite structures due to the high mechanical strength. Since the dynamic behavior of the composite systems has always been of interest to researchers, constructions produced from pervious concrete could be investigated under seismic loading (Daie *et al.* 2011, Ghassemieh and Bahadori 2015, BAHADORI and Ghassemieh 2016).

According to Grubeša (2018), pervious permeable and no-fines concrete has carried similar literal components like the standard concrete, but with more porosity and void content (11% - 35%) and the water permeability coefficient of 2–6 mm/s. PC is the mix of cement, water, and coarse aggregate, with low fine aggregates. Due to the essentiality of pore connectivity in PC function, the related compaction is limited. In this study, the typical properties of PC have been highlighted like good drainage, high noise absorption, urban heat reduction, poor mechanical properties, low abrasion and freeze-thaw resistance (Grubeša *et al.* 2018, Peng *et al.* 2018). Waste tire rubber disposal globally would become an environmental problem (around 1000 million inefficient ones with 50% no further treatment), providing the waste tire-rubber usage in cement based substances replaced some of the natural aggregates (Thomas *et al.* 2016). On the other hand, the transportation cost of waste tires is averagely around £1/ton/km based on European Tire Recycling Association (ETRA) (Toghroli *et al.* 2018). PC pavements (PCPs) has provided run-off water to penetrate the ground to reduce the flash flooding risks produced by storm water run-off and also the water PCPs raising have reduced pollutant concentration in penetrating the captured water. Kfoury *et al.* (2015) determined that implementation of PCPs can prevent 700 million dollar losses due to halting service sectors during expected 4 days of rain precipitation at the city of Dubai. PC as a macro-porous concrete has excessively gained popularity due to its sustainable construction usage as parking lot, garages, and small roads in Europe (Switzerland and England). Initial favorable porous pavement usage has been performed for parking lots and service road in US (Kuo *et al.* 2013). Recycled PC aggregate as a new type of ecologically concrete has reduced the pollutions, protecting the ecological balance (Zhang *et al.* 2017). Permeable pavement is one of the propose techniques in Low Impact Developments (LID) in US and Water Sensitive Urban Design (WSUD) in Australia to minimize the urbanized impact by reducing the runoff peak flowing and making water quality control to save downstream waterbodies, largely through the following of natural processes (Razzaghmanesh and Beecham 2018). The performance of CPCs when exposed to sand and dust storm, a common environmental condition in arid regions, has been examined by El-Hassan *et al.* (2017). The results revealed that a properly designed PCP remains permeable despite of frequent sand accumulation and dust settlement on the pavement surface. In case of noticeable reduction in concrete permeability due to sand and dust pore clogging at top layer of pavement, cleaning with water jet could successfully recover the perviousness of pavement. Lower unit weights have been compared to plain concrete, less applicability of rubbrerized concrete with coarse rubber particles, significant decline in final strength and vivid elasticity modulus. More ductile behavior has been gained for rubberized concrete in comparison to plain concrete specimen(s) in compression testing (Khaloo *et al.* 2008).

(a) (b) (c)

Fig. 2 (a) Waste tire, (b) Tire chip (TC) and (c) Crumb rubber (CR)

Total Municipal Solid Waste Generation in US has been illustrated (Fig. 1)(Thomas *et al.* 2016). Waste material usage by relatively replacement of cement in PC has reduced the cost of making concrete reducing the disposal problems of waste substances on cement usage for making PC. When cement has been substituted by different industrial wastes, compressive strength, flexural strength and split tensile strength and permeability of PC for different mixtures has depended on the waste materials' types used in PC making (TALSANIA *et al.* 2015). Usage of recycled aggregates from demolished concrete structures in PCPs was examined by Kianmehr *et al.* (2017). The results of compression and flexural tests revealed that the ratio of recycled aggregates should not exceed 30 percent of total aggregates. This limitation was mainly due to presence of weak aggregates and uncertainties associated with their adhesion to cementitious material in concrete mixture.

2. Categorizing waste rubber tyres

The rubber tires have been used by 3 various particle-size as very fine, fine and coarse including fine crumb rubber, crumb rubber (CR), tire chips (TC), replaced for cement and coarse aggregates. The concrete derived from rubber tire is named "rubberized concrete". Waste rubber tire, tire chip and CR are depicted in Figs. 2(a)-2(c) (Ghosh *et al.* 2015). Grinding and converting of tire rubber have been regarded as the most preferred method in tire recycling. CR concrete or asphalt pavement mixes have been sized (0.0075 mm - 4.75 mm), used in athletic tracks' outer surface, games, or its combinations such as asphalts (Thomas *et al.* 2016, Aoudia *et al.* 2017). (Gesoğlu *et al.* 2014b) has declared that the waste rubbers have been implemented in 3 diverse particle-size such as very fine, fine, and coarse, subsequently, TC in a gravity of 1.02 are applied as coarse rubber aggregate, while, 2 types of CR with nominal particle size (4 & 1 mm) are applied as fine aggregates in a 0.83 and 0.48 gravity. Despite technically viability, scrap tire usage in asphalt or other paving applications have been subsidized to compete the ordinary aggregate to meet the technical needs for asphalt pavement (Huang *et al.* 2007).

3. Properties of rubberized porous concrete

The rubber particles growing application as concrete aggregates has provoked the performance of rubberized PC in term of durability with low / limited strength resistance value (Shakrani *et al.* 2017). The mechanical properties of PC have indicated negative influence when waste rubber tires have been offered as its ingredients, say the rubber substances usage in PC has reduced its compressive strength and flexural strength, accordingly, despite of the compressive- strength reduction, it is in the approved range. Besides, the abrasion resistance and freeze thaw have been significantly improved; however, permeability is located within the confirmed curbs by using waste rubber tires, considered as fundamental required elements for PC pavement. So rubberized PC has been applied on less traffic roads, curbs, and shoulders (Ghosh *et al.* 2015). The strength reduction of rubberized concrete has brought prejudgments, however, the lower unit weight with higher sound and heat insulation, more resisting and roughness and raising flexibility features are the provisions juxtaposed with the ordinary concrete (Karakurt 2015).

3.1 Fresh concrete properties

3.1.1 Workability

(Eldin and Senouci 1993) have pioneered the research of aggregate obtained from the used tyres as the replacement of fine aggregate by the removed tyre rubber (size: 1 mm) and the replacement of coarse aggregate by discarded tyre rubber (size: 6, 19, 25 & 38 mm). The results have indicated the particular concrete with lower workability.

Mohammed *et al.* (2018) has studied the rubbercrete[1] made of partially replacement of fine aggregate in normal concrete with CR from scrap tires to optimize the mix ingredients turning out the rubbercrete to be more workable than the normal concrete (Mohammed *et al.* 2018). (Lv *et al.* 2015) has proved that the slump value of the fresh lightweight aggregate concrete has been declined by the raise of rubber-particles replacement because of the disorder shape and rough surface of rubber particles, respectively, the compressive-strength of RLAC[2] has

[1] Rubber-Concrete Composite

[2] Rubber Lightweight Aggregate Concrete

demonstrated a decline by raising the mixture ratio of the rubber particles content besides an increment with age. Furthermore, any minimizing in static modulus of elasticity has indicated great flexibility regarded as a favorable achievement in rubberized light-weight aggregate concrete mixes. In another study, (Thomas *et al.* 2016) has investigated the applicability of fresh concrete experimented in a compacting factor apparatus (IS 1199: 1959).

By growing percentages of concrete crumb rubber (CR), the density of the concrete has been declined because of the low specific gravity of CR compared to natural sand. Slump in fresh concrete mix has been reduced in high rubber waste mixture's contents. The drop in slump has depended on the amount and size of rubber particle in fresh concrete, respectively, in terms of size, the addition of rubber waste up to 10% has declined the slump (from 8.3 to 3.8 cm), and the addition of 20% rubber waste has decreased the slump (from 4.75 to 1.0 cm) (Toghroli *et al.* 2018). Also the study of (Benazzouk *et al.* 2006) has comprised the waste rubber particles of less than 1 mm (size) with approximate 20% polypropylene fibers. Consequently, total density of the rubber waste particle is 430 kg/m^3.

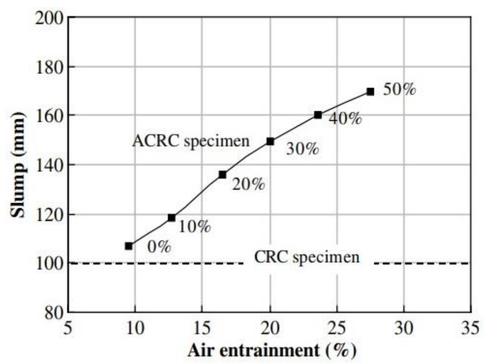

Fig. 3 Effect of air-entrainment on the slump of fresh composite containing different rubber volume ratios (0-50%)

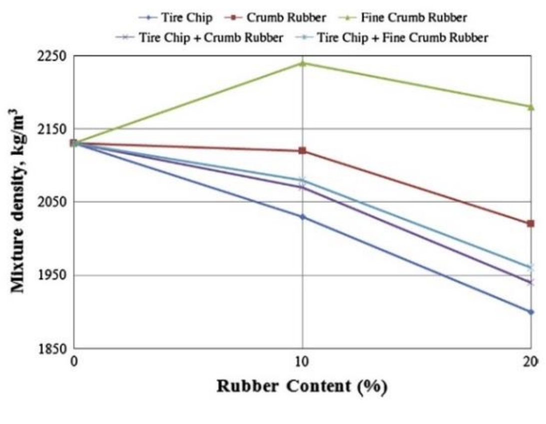

Fig. 4 Fresh density of PC versus rubber content

The composites derived from the application of the mentioned process have defined the cement rubber composite (CRC) and aerated cement rubber composite (ACRC). The applicability of fresh ACRC material has been significantly developed because of the generation of micro air bubbles on air-entraining agent addition. The influence of air-entrainment on the slump of a fresh aerated composite with changed rubber ratio has been offered (Fig. 3). (Li *et al.* 2004) has mentioned that 15% replacement of coarse aggregate through waste tire rubbers has reduced the influence of tire rubber wastes on the applicability of the changed concrete discarding chips / fiber.

3.1.2 Bulk density

By focusing on PC properties, (Gesoğlu *et al.* 2014b) has indicated that control PC has a density of 2130 kg/m^3 (80% of normal concrete weight). Adding different rates of rubber has provided lighter concretes (Fig. 4) in a way that the rubberized PC densities are less than the control mixed one by 2–11%. The least density (1900 kg/m^3) is gained from the mix of 20 TC, but the highest density (2240 kg/m^3) has belonged to the mix of 20 FCR, therefore, the rubberized concrete mixes are somehow applicable. Also the light weight concretes of air-entrainment in the fresh concrete have been increased by the minimized rubber particle size. Fresh concrete with rubber waste fraction 1/2 added to the 30 % of total aggregate (amount) has comprised the average air-entrainment of 5.3%, while samples with rubber waste fraction 0/1 have comprised air entrainment of 14.0% (Toghroli *et al.* 2018). Also, (Chandrappa and Biligiri 2016) have studied that adding of polymers and rubber have raised the fracture roughness of the material because of the ductility increment. The use of waste hardened concrete as a recycled aggregate on PC production has been investigated by Aliabdo *et al.* (2018). The effect of recycled concrete aggregate usage as a coarse aggregates replacement on fresh and hardened density has been depicted (Fig. 4), accordingly, using recycled concrete aggregates have relatively decreased the fresh and hardened density. Adding rubber particles in cement matrix has increased the air entrainment ratio, also the value range for CRC[3] and ACRC[4] specimen in 50% rubber volume level is (17.0% - 28.2%). For cement paste, air-entrainment has been changed (from 2.0% to 9.5%) in the same order (Benazzouk *et al.* 2006).

3.2 Hardened concrete characteristics

3.2.1 Compressive strength

The modification of PC properties by CR has indicated that the rubber adding has slightly decreased the strength and permeability, while significantly enhanced the ductility and freeze-thaw resistances (Liu *et al.* 2018), accordingly, the compressive-strength has been decreased by the raising of rubber incorporation range. Though the rubber addition has reduced the compressive strength of PC,

[3] Cement-Rubber Composite

[4] Arated Cement-Rubber Composite

the requirements of non-structural use have been met yet. (Khaloo *et al.* 2008) has observed more ductile behavior for rubberized concrete juxtaposed with the plain concrete specimen in compression testing. Another study conducted by Al-fadhl *et al.* (2017) has mentioned that the replacement of mineral aggregate by tire rubber particle in concrete has excessively reduced the final strength and tangential modulus of elasticity (Gesoğlu *et al.* 2014b). Mehmet *et al.* (2014) has investigated PC properties including waste tires proving that by using tire chips and CR, the compressive strength of porous concrete is 6.45 MPa, whereas, the compressive strength of PC is 3 to 30 MPa. However, CR has probably been used for the partially replacement of natural fine aggregate up to 7.5% with no adequate decline in its desired strength (Thomas *et al.* 2016). Meanwhile, (Biligiri and Mondal 2018) in their study have verified the hydrological, functional, and structural properties of 21 PC mixes encompassing 4 dosages of CR, 4 silica fume (SF) proportions, and 3 distinct aggregate gradation. Totally, 126 PC cylindrical tests have been performed to calculate density, porosity, permeability, abrasion resistance, and compressive strength, also their inclusion (CR & SF) in PC has made the compressive strength and abrasion resisting juxtaposed with the control original PC specimen. (Skripkiūnas *et al.* 2010) has also indicated that the compressive strength of rubberized concrete has depended on the rubber-waste's content and size which is reduced by more content and smaller size. (Xue and Shinozuka 2013) have declared the integration of cement paste and CR has been developed through the SF addition in concrete confirmed by the compressive-strength increment in rubberized SF concrete. (Ganjian *et al.* 2009) has investigated scrap tire rubber as a concrete aggregate, then the concrete mixtures' strength including chipped rubber has been decreased. Regarding the powder rubber replacement as 5%, the compressive-strength has been declined about 5% compared to the control mixture with 5% (weight) falling down in cement content. A replacement of 7.5% and 10% of powder rubber have decreased the strength about 10% to 23%, due to the cement reduction within the mixtures. (Warudkar and Valekar 2015) have investigated the concrete properties through the waste rubber as coarse aggregate, resulting that the compressive strength of rubberized concrete is low compared to normal concretes in the confirmed borders. The flexural strength has been decreased compared to normal concrete; however, the rubberish concrete cost is lower than normal concrete. High-strength rubber concrete has also been gained by magnesium oxychloride cement providing favourable bonding properties to rubber and essentially improving the rubbercrete performing. Furthermore, adhesion between rubber particles and other constituents substances have been surpassed by pre-treating the rubber aggregate with magnesium oxychloride (Siddique and Naik 2004). (Son *et al.* 2011) has studied the strength of PC by using waste rubber tire indicating that the compressive capacity of 24 MPa concrete has been decreased to 8 and 32% by 0.5 and 1% rubber particle addition to concrete mixture. Likewise, 0.5 and 1% rubber particle usage in the 28 MPa concrete mix has produced a 14% and 18% decline in the compressive capacity of the column specimen. Another study has been conducted by (Mohammed and Adamu 2018) on roller-compacted rubbercrete by using the combined Son Reb and response surface methodology indicating that the compressive-strength, UPV[5], RN[6] and DMOE[7] of RCR[8] have been declined by the increase of replacement percentage of fine aggregate with CR[9] above 10%. The addition of NS[10] up to 2% has increased the compressive-strength, UPV, RN, and DMOE of RCR.

3.2.2 Flexural tensile strength

The flexural strength values from 2.16 to 0.40 MPa have indicated the highest strength value for control concrete (Fig. 5). Addition of rubber to PC has negatively influenced the flexural strength as in ordinary concrete providing a systematic decline by the rubber content's increment. When the rubber is substituted by natural aggregates, weak bonds between the cement paste and rubber particles have been formed compared to the stronger bonds between cement paste and aggregates. Therefore, based on the research, the rubber size is highly effectual on the flexural strength than the rubber content. PC with fine CR has provided the least flexural strength (Gesoğlu *et al.* 2014a). (Aliabdo *et al.* 2018) has defined the influence of recycled rubber aggregate's substitute ratio on the PC flexural strength. Based on the Fig. 5, any growing of substitute ratio of recycled aggregates has decreased the flexural strength of PC. The flexural strength reduction ratio because of recycled aggregate usage at 50%, 100% replacement level is 18.8% and 41.2%, therefore, on using 9.5 mm aggregate size, the flexural strength decreasing ratio is 34% and 54% to the 19 mm aggregate size usage, which is a behaviour similar to splitting tensile strength (Fig. 5). Adverse influence of the recycled aggregate's usage might be subjected to the weak properties of transition zone toward the recycled aggregates. Also, the transition zone has highly affected the concrete tensile strength.

3.2.3 Abrasion resistant

(Thomas *et al.* 2016) has studied the abrasion concrete resistance including waste rubber tire particles. The results have shown a favorable resisting of rubberized concrete in abrasion than the control mix. When the water cement range is 0.4, abrasion depth is 1.41 mm for control mixture and the abrasion depth for all mixtures up to 20%, the CR replacement is lower than 1.41 mm. (Kang *et al.* 2012) has also studied the abrasion resisting of rubberized concretes, so SF and CR are additives, in other words, SF has made the compressive strength and abrasion concrete resistances, so addition of CR has lessen the compressive strength, however, the abrasion concrete resistance has been inclined. SF concrete has provided a favourable abrasion resistance than control concrete, and the rubberized concrete has done

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[5] Ultrasonic Pulse Velocity
[6] Rebound Number
[7] Dynamic Modulus of Elasticity
[8] Roller-compacted Rubbercrete
[9] Crumb Rubber
[10] Nano Silica

a satisfied abrasion resisting than SF concrete. (Pedro *et al.* 2018) has studied the durability performance of high performance concrete from the recycled aggregate, subsequently, 3 subsets of concrete with densified SF proportions of 0%, 5% and 10% (in addition to cement) have been taken. The results have shown that applied FRA[11] and CRA[12] have carried out the needs based on the European standards in terms of using recycled aggregate in concrete.

3.2.4 Water absorption, sorptivity and penetration

According to (Güneyisi *et al.* 2016), substituting the natural aggregate with recycled aggregate has resulted permeability coefficient raising, however, the mechanical properties of such concretes have been negatively affected up to a certain degree. (Liu *et al.* 2018) has shown the varieties of the permeability coefficient of PC vs rubber content (Fig. 6), thereafter, the addition of rubber has decreased the absorption for control mixture of 2.89%, so in a mixture with 10% CR is 3.15% and in a mix with 20% CR is 3.32%. The same pattern has been gained in the series with water cement ranges of 0.45 and 0.50. (Gesoğlu *et al.* 2014b) has observed that the permeability of PC has fallen down into 0.25 - 0.61 cm/s, recommending the pervious concrete limitations. (Aliabdo *et al.* 2018) has also indicated the effects of rubber fibers content on PC permeability (Fig. 7). According to the outcome, raising of rubber fibers content has increased the PC permeability, occurred because of the PC density reduction in the result of using rubber fibers as coarse aggregates. Comparing to control mix, an increase in PC permeability is 5.5% and 10.3% for 1.5% and 3% rubber fiber. (Gesoğlu *et al.* 2014b) has investigated about the mechanical characteristics and permeability, then three rubber types have been applied in producing the rubberized plain PC mixtures gained by some replacement of the rubber aggregate, furthermore, using of rubber has significantly aggravated the mechanical characteristics and PC permeability, but in various degrees based on the applied rubber's type and rate.

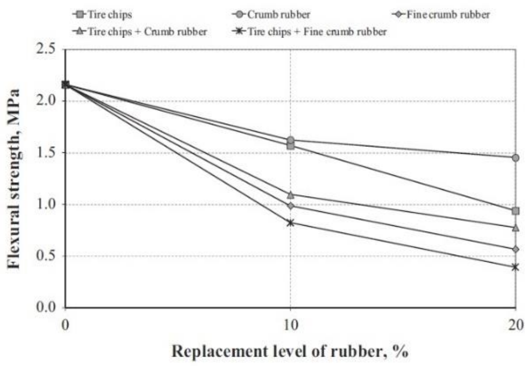

Fig. 5 Flexural strength of pervious concrete vs rubber replacement ratio

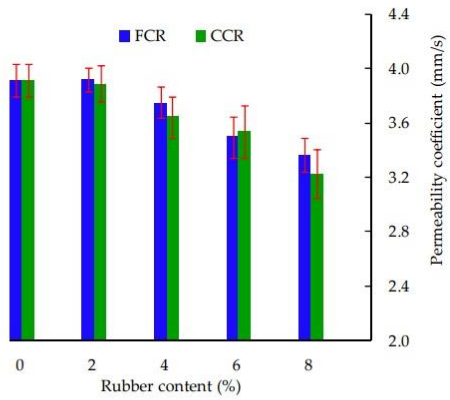

Fig. 6 The permeability coefficient of RMPC versus rubber content

3.2.5 Modules of elasticity

Typically, the replacement of rubber particle for aggregate and cement have reduced the modulus of concrete elasticity (Ganjian *et al.* 2009). (Gesoğlu *et al.* 2014b) has defined that the natural aggregate replacement by rubber particles has significantly increased the roughness and ductility of concrete beside the favorable damping capacity. The results have also indicated the incorporated PC with rubbers has a lower splitting tensile strength, modulus of elasticity, compressive strength of 3-30 MPa and permeability of 0.025-0.61 cm/s. In contrast, an obvious increment in the roughness, ductility and damping capacity of PC with rubbers have been observed. Application possibilities are in parking lots, crosses and road shoulders. The results of dynamic elasticity modulus of ACRC[13] and CRC[14] samples vs rubber particle content have been illustrated (Fig. 8) indicating a 50% rubber volume level. Besides, the dynamic features of elasticity on aerating a composite has been decreased about 6.2 to 3.7 GPa correspondent to 40.3% reduction. However, rubber has favoured the absorption of ultrasonic waves (Benazzouk *et al. 2006).* Accordingly, (Alaloul *et al.* 2018) has illustrated the results of the Modulus of Elasticity and Poisson's Ratio of concrete including CR. Any increasing in Nano silica ratio has increased the elasticity modulus and Poisson's ratio, because Nano silica is a pozzolanic material carrying the characteristics of a filler effect when reacted with portlandites matrix.

3.2.6 Freeze-thaw resistance

PC with macro-pore structure normally keeps water in the pores and might undergo F–T[15] cycles deteriorating the material. F–T resistance has been calculated based on mass loss after a few successive freeze and thaw cycles. To determine the quantity of F–T resistance, various additives have been used (Toghroli *et al.* 2018). (Yang and Jiang 2003) have indicated that SF with super plasticizer has improved

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[11] Fine Recycled aggregates
[12] coarse recycled aggregates
[13] Aerated Cement–Rubber Composite
[14] Cement–Rubber Composite
[15] Freeze-thaw

F–T resisting. Tire chips and CR are utilized to surpass the

affected the PC abrasion and freeze–thaw resistance.

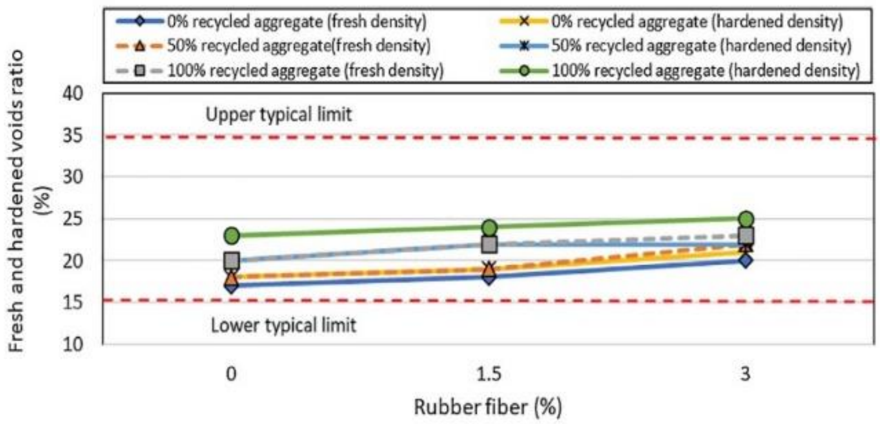

Fig. 7 Effect of rubber fiber on PC voids ratio

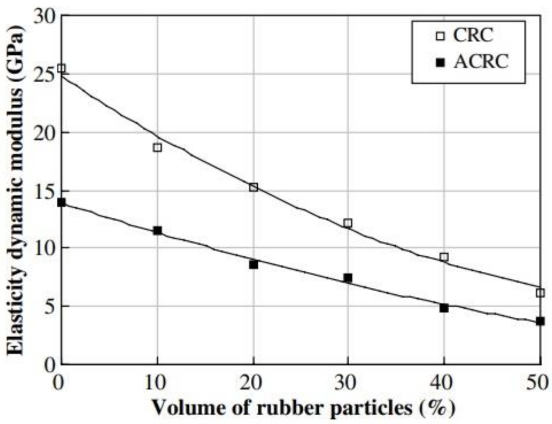

Fig. 8 Elasticity dynamic variations with rubber particles' volume ratio

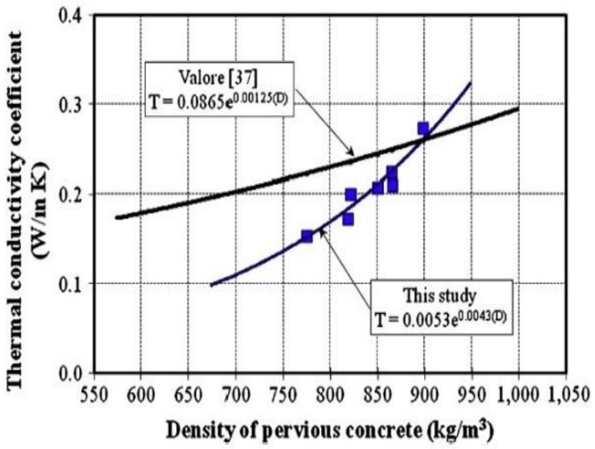

Fig. 9 The relations of density and thermal conductivity coefficient of LWCP

F–T resisting. Accordingly, the study on abrasion and freezing thawing resistance of PC by (Gesoğlu *et al.* 2014a) has shown that the rubber size and content have positively

Flexural strength reduction has been observed in rubber addition. The rubber usage after 300 freezing thawing cycles has been remarkably improved; also the rubber usage in various sizes and amounts has developed the surface property of PC through favourable abrasion resistance results in terms of wear-deep. (Toghroli *et al.* 2018) has declared that the frost resistance factor (Kf) has been applied in designing the composition of frost resistant concrete. in other words, adding rubber wastes have increased the closed porosity and frost resistant concrete provided no air-entraining agents through the control of cement parameters and rubberized-concrete. (Lund *et al.* 2018) has investigated the PC freeze thaw durability. In this research, the freeze-thaw durability of one PC baseline mix designed with 3 diverse entrained air levels have been evaluated through the use of operational modal analysis. Adding air entrainment has increased the PC applicability, so the void content has been reduced and the compressive-strength has been inclined. The effect of entrained air level in the cement paste on compressive-strength is not significant juxtaposed with the influence of void content.

3.2.7 Thermal and acoustic properties

(Khaloo *et al.* 2008) has investigated the feasibility of applying of elastic and flexible tire rubber aggregates in concrete, replaced as 12.5%, 25%, 37.5%, and 50% of total mineral aggregates in concrete. Tire–rubber concrete has potentially used in sound dampening and other shaking energies as sound insulation. (Chindaprasirt *et al.* 2015) has investigated the outcomes of thermal conductivity coefficient and weight reduction from abrasion test of light weight PC, then all light weight PC has lower thermal conductivity in 0.15 to 0.27 W/mK[16] based on the content and type of additions because of the high porosity with less density of light weight aggregates and high void content of light weight PC. Also, (Chindaprasirt *et al.* 2015) has declared that the acoustic qualities of different materials would be verified based on the air flow resisting variations.

[16] watts per meter-kelvin

The acoustic parameters of porous materials like foam gypsum slag, foam slag concrete and foam ceramic have been gained as frequency, porosity and the pores character. Porous and fibrous materials have been varied by porosity and macro-structure. (Licitra *et al.* 2019) has investigated the acoustic ageing of few rubberized road surfaces maintained based on the wet process laid on 3 various sites. Linear and logarithmic regression methods are used to say the acoustic ageing of the rubberized pavement. Rubberized asphalt pavement has been designed by an aggregate gradation finer with low susceptible to the acoustic ageing parameters. The analysis results of heat gain of a PCPC[17] system compared to a PCC[18] system have hypothesised that PC has behaved similarly to traditional concrete with similar material mix regarding the gain and loss of heat in summer days with less/no precipitation regardless of lower SRI[19] in PC pavement (Haselbach *et al.* 2011). A study conducted by Park *et al.* (2015) has evaluated the physical and mechanical characteristics of sound absorption of porous concrete. Another study about the properties of sound absorption of the porous concrete by applying the recycled waste concrete aggregate has been conducted by (Park *et al.* 2005), resulting that the Noise Reduction Coefficient (NRC) is optimal at the void range of 25%, however, the percentage content of the recycled aggregates has low impact on NRC. Moreover, the optimal void range is 25% and the recycled aggregate is 50%. Acoustic qualities of different substances have been verified based on the air-flow resisting changes.

4. Conclusions

Using PC combined with scrap rubber tires as pavement is highly provisional in urban areas due to both intrinsic mechanical properties of porous concrete and environmental benefits of re-usage of waste rubber tires providing:

- Essential investigations on the properties of rubberized PC to meet the requirements of pavement porous concrete. In the following,
- Lack of compressive-strength and elasticity-modules of rubberized PC have also been observed.
- More ductile behaviors of the mentioned pavement concrete have led to lower bulk density and also lower tensile split.
- Consequently, using rubber in PC has reduced the permeability coefficient.
- On the other hand, the abrasion resistance has been improved when rubber is mixed in PC.
- Appropriate rubber size with additives has positively affected the rubberized PC mitigating the acoustic emissions.
- Rubberized PC has been taken as a highly promising material for pavements. Both mechanical and technical properties have been fulfilled within the required standards in low-volume pavements as a considerable achievement in sustainable construction.

[17] Portland Cement Pervious Concrete
[18] Portland Cement Concrete
[19] Solar Reflectance Index

References

Abedini, M., *et al.* (2017), "Evaluation of concrete structures reinforced with fiber reinforced polymers bars: A review", *J. Asian Sci. Res.*, **7**(5), 165.

Abedini, M., *et al.* (2019), "Large Deflection Behavior Effect in Reinforced Concrete Columns Exposed to Extreme Dynamic Loads", Loads, engrXiv: 32.

Alaloul, W. S., *et al.* (2018), "Defotmation properties of concrete containing crumb rubber as partial replacement to fine aggregate", *Technology*, **9**(10), 317-326.

Aliabdo, A.A., *et al.* (2018), "Experimental investigation on permeability indices and strength of modified pervious concrete with recycled concrete aggregate", *Constr. Build. Mater.*, **193**: 105-127. https://doi.org/10.1016/j.conbuildmat.2018.10.182.

Aoudia, K., *et al.* (2017), "Recycling of waste tire rubber: Microwave devulcanization and incorporation in a thermoset resin", *Waste Management*, **60**, 471-481. https://doi.org/10.1016/j.wasman.2016.10.051.

Arabnejad Khanouki, M.M., *et al.* (2010), "Investigation of seismic behaviour of composite structures with concrete filled square steel tubular (CFSST) column by push-over and time-history analyses", *Proceedings of the 4th International Conference on Steel & Composite Structures*.

Arabnejad Khanouki, M.M., *et al.* (2011), "Behavior of through beam connections composed of CFSST columns and steel beams by finite element sudying", *Adv. Mater. Res.*, **168**, 2329-2333.

Arabnejad Khanouki, M.M., *et al.* (2016a), "Investigation of through beam connection to concrete filled circular steel tube (CFCST) column", *J. Constr. Steel Res.*, **121**, 144-162.

Bahadori, A. and Ghassemieh, M. (2016), "Seismic evaluation of I-shaped beam to box-column connections with top and seat plates by the component method", Sharif: Civil Engineering **322**(21), 129-138.

Bahari, A., *et al.* (2018), "Experimental and theoretical studies of ordinary Portland cement composites contains nano LSCO perovskite with Fokker-Planck and chemical reaction equations", *Constr. Build. Mater.*, **163**, 247-255.

Bahari, A., *et al.* (2012), "Synthesis and strength study of cement mortars containing sic nano particles", *Digest J. Nanomaterials & Biostructures (DJNB)*, **7**(4), 1427-1435

Batayneh, M., *et al.* (2007), "Use of selected waste materials in concrete mixes", *Waste Management*, **27**(12), 1870-1876. https://doi.org/10.1016/j.wasman.2006.07.026.

Benazzouk, A., *et al.* (2006), "Physico-mechanical properties of aerated cement composites containing shredded rubber waste", *Cement Concrete Compos.*, **28**(7), 650-657. https://doi.org/10.1016/j.cemconcomp.2006.05.006.

Biligiri, K.P. and Mondal, S. (2018), "Crumb rubber and silica fume inclusions in pervious concrete pavement systems: evaluation of hydrological, functional, and structural properties", *J. Test. Evaluation*, **46**(3). DOI: 10.1520/JTE20170032.

Chandrappa, A.K. andBiligiri, K.P. (2016), "Pervious concrete as a sustainable pavement material–Research findings and future prospects: A state-of-the-art review", *Constr. Build. Mater.*, **111**, 262-274. https://doi.org/10.1016/j.conbuildmat.2016.02.054.

Chen, C., *et al.* (2019), "Behavior of steel storage pallet racking connection-A review", *Steel Compos. Struct.*, **30**(5), 457-469.

https://doi.org/10.12989/scs.2019.30.5.457.
Chindaprasirt, P., *et al.* (2015), "Mechanical and thermal properties of recycling lightweight pervious concrete", *Arabian J. Sci. Eng*., **40**(2), 443-450. https://doi.org/10.1007/s13369-014-1563-z.
Daie, M., *et al.* (2011), "A new finite element investigation on pre-bent steel strips as damper for vibration control", *Int. J. Phys. Sci*., **6**(36), 8044-8050.
Davoodnabi, S.M., *et al.* (2019), "Behavior of steel-concrete composite beam using angle shear connectors at fire condition", *Steel Compos. Struct*., **30**(2), 141-147. https://doi.org/10.12989/scs.2019.30.2.141.
Eldin, N.N. and Senouci, A.B. (1993), "Observations on rubberized concrete behavior", *Cement, Concrete Aggregates*, **15**(1), 74-84. DOI: 10.1520/CCA10590J.
Ganjian, E., *et al.* (2015), "Using waste materials and by-products to produce concrete paving blocks", *Constr. Build. Mater*., **77**, 270-275. https://doi.org/10.1016/j.conbuildmat.2014.12.048.
Ganjian, E., *et al.* (2009), "Scrap-tyre-rubber replacement for aggregate and filler in concrete", *Constr. Build. Mater*., **23**(5), 1828-1836. https://doi.org/10.1016/j.conbuildmat.2008.09.020.
Gesoğlu, M., *et al.* (2014a). "Abrasion and freezing–thawing resistance of pervious concretes containing waste rubbers", *Constr. Build. Mater*., **73**, 19-24. https://doi.org/10.1016/j.conbuildmat.2014.09.047.
Gesoğlu, M., *et al.* (2014b), "Investigating properties of pervious concretes containing waste tire rubbers", *Constr. Build. Mater*., **63**, 206-213. https://doi.org/10.1016/j.conbuildmat.2014.04.046.
Ghassemieh, M. and Bahadori, A. (2015), "Seismic evaluation of a steel moment frame with cover plate connection considering flexibility by component method", *Proceedings of the 2015 world congress on Advances in Structural Engineering and Mechanics*, Incheon, Korea.
Ghosh, S.K., *et al.* (2015), "A review on performance of pervious concrete using waste materials", IJRET, eISSN, 2319-1163.
Grubeša, I.N., *et al.* (2018), "Draining capability of single-sized pervious concrete", *Constr. Build. Mater*., **169**, 252-260. https://doi.org/10.1016/j.conbuildmat.2018.03.037.
Güneyisi, E., *et al.* (2016), "Effect of different substitution of natural aggregate by recycled aggregate on performance characteristics of pervious concrete", *Mater. Struct*., **49**(1-2), 521-536. https://doi.org/10.1617/s11527-014-0517-y.
Hager, A.S. (2009), Sustainable design of pervious concrete pavements, University of Colorado at Denver.
Hamdia, K. M., *et al.* (2015), "Predicting the fracture toughness of PNCs: A stochastic approach based on ANN and ANFIS", *Comput. Mater. Sci*., **102**, 304-313.
Hamidian, M., *et al.* (2012), "Application of Schmidt rebound hammer and ultrasonic pulse velocity techniques for structural health monitoring", *Sci. Res. Essays*, **7**(21), 1997-2001.
Hamidian, M., *et al.* (2011), "Assessment of high strength and light weight aggregate concrete properties using ultrasonic pulse velocity technique", *Int. J. Phys. Sci*., **6**(22), 5261-5266.
Haselbach, L., *et al.* (2011), "Cyclic heat island impacts on traditional versus pervious concrete pavement systems", *Transportation Res. Record*, **2240**(1), 107-115. https://doi.org/10.3141/2240-14.
Heydari, A. and Shariati, M. (2018), "Buckling analysis of tapered BDFGM nano-beam under variable axial compression resting on elastic medium", *Struct. Eng. Mech.*, **66**(6), 737-748. https://doi.org/10.12989/sem.2018.66.6.737.
Ho-Huu, V., *et al.* (2018), "An efficient procedure for lightweight optimal design of composite laminated beams", *Steel Compos. Struct*., **27**(3), 297-310. https://doi.org/10.12989/scs.2018.27.3.297.
Hosseinpour, E., *et al.* (2018), "Direct shear behavior of concrete filled hollow steel tube shear connector for slim-floor steel beams", *Steel Compos. Struct*., **26**(4), 485-499. https://doi.org/10.12989/scs.2018.26.4.485.
Huang, Y., *et al.* (2007), "A review of the use of recycled solid waste materials in asphalt pavements", *Resour. Conserv. Recy*., **52**(1), 58-73. https://doi.org/10.1016/j.resconrec.2007.02.002.
Kang, J., *et al.* (2012), "The abrasion-resistance investigation of rubberized concrete", *J. Wuhan Univ. Technology-Mater. Sci. Ed.*, **27**(6), 1144-1148. https://doi.org/10.1007/s11595-012-0619-8.
Karakurt, C. (2015), "Microstructure properties of waste tire rubber composites: an overview", *J. Mater. Cycles Waste Management*, **17**(3), 422-433. https://doi.org/10.1007/s10163-014-0263-9.
Katebi, J., *et al.* (2019), "Developed comparative analysis of metaheuristic optimization algorithms for optimal active control of structures", *Engineering with Computers*, 1-20.
Khalilpasha, M. H., *et al.* (2012), "Sustainable development using recyclable rubber in Self-Compacting Concrete", *Proceedings of the 3rd international conference on construction in developing countries (advancing civil, architectural and construction engineering and management)*, Bangkok, Thailand.
Khaloo, A.R., *et al.* (2008), "Mechanical properties of concrete containing a high volume of tire–rubber particles", *Waste Management*, **28**(12), 2472-2482. https://doi.org/10.1016/j.wasman.2008.01.015.
Khorami, M., *et al.* (2017a), "Seismic performance evaluation of buckling restrained braced frames (BRBF) using incremental nonlinear dynamic analysis method (IDA)", *Earthq. Struct.*, **13**(6), 531-538.
Khorami, M., *et al.* (2017b), "Evaluation of the seismic performance of special moment frames using incremental nonlinear dynamic analysis", *Struct. Eng. Mech*., **63**(2), 259-268. https://doi.org/10.12989/sem.2017.63.2.259.
Khorramian, K., *et al.* (2017), "Numerical analysis of tilted angle shear connectors in steel-concrete composite systems", *Steel Compos. Struct*., **23**(1), 67-85. https://doi.org/10.12989/scs.2017.23.1.067.
Khorramian, K., *et al.* (2015), "Behavior of tilted angle shear connectors", *PLoS ONE*, **10**(12), 1-11. https://doi.org/10.1371/journal.pone.0144288.
Khorramian, K., *et al.* (2016), "Behavior of Tilted Angle Shear Connectors (vol 10, e0144288, 2015)", *PLoS ONE*, **11**(2).
Kia, A., *et al.* (2018), "Defining clogging potential for permeable concrete", *J. Environ, Management*, **220**, 44-53. https://doi.org/10.1016/j.jenvman.2018.05.016.
Kuo, W.T., *et al.* (2013), "Use of washed municipal solid waste incinerator bottom ash in pervious concrete", *Cement Concrete Compos*., **37**, 328-335. https://doi.org/10.1016/j.cemconcomp.2013.01.001.
Li, D., *et al.* (2019), "Application of polymer, silica-fume and crushed rubber in the production of Pervious concrete", *Smart Struct. Syst*., **23**(2), 207-214. https://doi.org/10.12989/sss.2019.23.2.207.
Li, G., *et al.* (2004), "Development of waste tire modified concrete", *Cement Concrete Res*., **34**(12), 2283-2289. https://doi.org/10.1016/j.cemconres.2004.04.013.
Licitra, G., *et al.* (2019), "Modelling of acoustic ageing of rubberized pavements", *Appl. Acoust*. **146**, 237-245. https://doi.org/10.1016/j.apacoust.2018.11.009.
Liu, H., *et al.* (2018), "Mechanical properties, permeability, and freeze–thaw resistance of pervious concrete modified by waste crumb rubbers", *Appl. Sciences*, **8**(10), 1843. https://doi.org/10.3390/app8101843.
Lund, M., *et al.* (2018), "Evaluation of freeze-thaw durability of pervious concrete by use of operational modal analysis", *Cement Concrete Res*., **106**, 57-64. https://doi.org/10.1016/j.cemconres.2018.01.021.

Luo, Z., *et al.* (2019), "Computational and experimental analysis of beam to column joints reinforced with CFRP plates", *Steel Compos. Struct.*, **30**(3), 271-280. https://doi.org/10.12989/scs.2019.30.3.271.

Lv, J., *et al.* (2015), "Effects of rubber particles on mechanical properties of lightweight aggregate concrete", *Constr. Build. Mater.*, **91**, 145-149. https://doi.org/10.1016/j.conbuildmat.2015.05.038.

Mansouri, I., *et al.* (2016), "Strength prediction of rotary brace damper using MLR and MARS", *Struct. Eng. Mech.*, **60**(3), 471-488. http://dx.doi.org/10.12989/sem.2016.60.3.471.

Mansouri, I., *et al.* (2019), "Analysis of influential factors for predicting the shear strength of a V-shaped angle shear connector in composite beams using an adaptive neuro-fuzzy technique", *J. Intell. Manufact.*, **30**(3), 1247-1257.

Mohammadhassani, M., *et al.* (2014a), "An experimental study on the failure modes of high strength concrete beams with particular references to variation of the tensile reinforcement ratio", *Eng. Fail. Anal.*, **41**, 73-80. https://doi.org/10.1016/j.engfailanal.2013.08.014.

Mohammadhassani, M., *et al.* (2014b), "An evolutionary fuzzy modelling approach and comparison of different methods for shear strength prediction of high-strength concrete beams without stirrups", *Smart Struct. Syst.*, **14**(5), 785-809. http://dx.doi.org/10.12989/sss.2014.14.5.785.

Mohammadhassani, M., *et al.* (2014c), "Ductility and strength assessment of HSC beams with varying of tensile reinforcement ratios", *Struct. Eng. Mech.*, **48**(6), 833-848. http://dx.doi.org/10.12989/sem.2013.48.6.833.

Mohammadhassani, M., *et al.* (2015), "Fuzzy modelling approach for shear strength prediction of RC deep beams", *Smart Struct. Syst.*, **16**(3), 497-519. http://dx.doi.org/10.12989/sss.2015.16.3.497.

Mohammed, B.S. and Adamu, M. (2018), "Non-destructive evaluation of nano silica-modified roller-compacted rubbercrete using combined SonReb and response surface methodology", *Road Mater. Pavement Design*, 1-21. https://doi.org/10.1080/14680629.2017.1417891.

Mohammed, B.S., *et al.* (2018), "Rubbercrete mixture optimization using response surface methodology", *J. Cleaner Production*, **171**, 1605-1621. https://doi.org/10.1016/j.jclepro.2017.10.102.

Nasrollahi, S., *et al.* (2018), "Investigation of pipe shear connectors using push out test", *Steel Compos. Struct.*, **27**(5), 537-543. http://dx.doi.org/10.12989/scs.2018.27.5.537.

Neithalath, N., *et al.* (2010), "Characterizing pore volume, sizes, and connectivity in pervious concretes for permeability prediction", *Mater. characterization*, **61**(8), 802-813. https://doi.org/10.1016/j.matchar.2010.05.004.

Nguyen-Sy, T., *et al.* (2017), "A multi-scale homogenization approach for the effective thermal conductivity of dry lime–hemp concrete", *J. Build. Perform. Simul.*, **11**(2), 179-189. https://doi.org/10.1080/19401493.2017.1323009.

Nosrati, A., *et al*. (2018), "Portland cement structure and its major oxides and fineness", *Smart Struct. Syst.*, **22**(4), 425-432. https://doi.org/10.12989/sss.2018.22.4.425.

Park, S. B., *et al.* (2005), "Studies on the sound absorption characteristics of porous concrete based on the content of recycled aggregate and target void ratio", *Cement Concrete Res.*, **35**(9), 1846-1854. https://doi.org/10.1016/j.cemconres.2004.12.009.

Pedro, D., *et al.* (2018), "Durability performance of high-performance concrete made with recycled aggregates, fly ash and densified silica fume", *Cement Concrete Compos*., **93**, 63-74. https://doi.org/10.1016/j.cemconcomp.2018.07.002.

Peng, H., *et al.* (2018), "Mechanical and hydraulic behaviors of eco-friendly pervious concrete incorporating fly ash and blast furnace slag", *Appl. Sciences*, **8**(6), 859. https://doi.org/10.3390/app8060859.

Razzaghmanesh, M. and S. Beecham (2018), "A review of permeable pavement clogging investigations and recommended maintenance regimes", *Water*, **10**(3), 337. https://doi.org/10.3390/w10030337.

Safa, M., *et al.* (2016), "Potential of adaptive neuro fuzzy inference system for evaluating the factors affecting steel-concrete composite beam's shear strength", *Steel Compos Struct*., **21**(3), 679-688. http://dx.doi.org/10.12989/scs.2016.21.3.679.

Sadeghi-Nik, A., *et al.* (2012), "Effect of lanthanum oxide on the bases of cement and concrete", *Proceedings of the 3rd international conference on construction in developing countries (Advancing Civil, Architectural and Construction Engineering & Management)*, Bangkok, Thailand, July.

Sadeghi-Nik, A., *et al.* (2017), "Modification of microstructure and mechanical properties of cement by nanoparticles through a sustainable development approach", *Constr. Build. Mater.*, **155**: 880-891.

Sajedi, F. and M. Shariati (2019), "Behavior study of NC and HSC RCCs confined by GRP casing and CFRP wrapping", *Steel Compos. Struct*., **30**(5), 417-432. https://doi.org/10.12989/scs.2019.30.5.417.

Sari, P. A., *et al.* (2018), "An intelligent based-model role to simulate the factor of safe slope by support vector regression", *Engineering with Computers*, 1-11.

Sedghi, Y., *et al.* (2018), "Application of ANFIS technique on performance of C and L shaped angle shear connectors", *Smart Struct. Syst*., **22**(3), 335-340. https://doi.org/10.12989/sss.2018.22.3.335.

Shah, S., *et al.* (2016), "Behavior of steel pallet rack beam-to-column connections at elevated temperatures", *Thin-Walled Struct*., **106**, 471-483.

Shahabi, S., *et al.* (2016a), "Performance of shear connectors at elevated temperatures-A review", *Steel Compos. Struct*., **20**(1), 185-203. http://dx.doi.org/10.12989/scs.2016.20.1.185.

Shahabi, S., *et al.* (2016b), "Numerical analysis of channel connectors under fire and a comparison of performance with different types of shear connectors subjected to fire", *Steel Compos. Struct*., **20**(3), 651-669. http://dx.doi.org/10.12989/scs.2016.20.3.651.

Shakrani, S.A., *et al.* (2017), "Applications of waste material in the pervious concrete pavement: A review", AIP Conference Proceedings.

Shao, Z., Wakil, K., Usak, M., Amin Heidari, M., Wang, B. and Simoes, R. (2018), "Kriging Empirical Mode Decomposition via support vector machine learning technique for autonomous operation diagnosing of CHP in microgrid", *Appl. Therm. Eng*., **145**, 58-70.

Shao, Z. and Vesel, A. (2015), "Modeling the packing coloring problem of graphs", *Appl. Math. Model*., **39**(13), 3588-3595.

Shao, Z., Gholamalizadeh, E., Boghosian, A., Askarian, B. and Liu, Z. (2019), "The chiller's electricity consumption simulation by considering the demand response program in power system", *Appl. Therm. Eng*.,**149**, 1114-1124.

Shariati, A. (2014), Behaviour of C-shaped Angle Shear Connectors in High Strength Concrete, M.SC, Jabatan Kejuruteraan Awam, Fakulti Kejuruteraan, Universiti Malaya.

Shariati, A., *et al.* (2012a), "Investigation of channel shear connectors for composite concrete and steel T-beam", *Int. J. Phys. Sci.*,**7**(11), 1828-1831. DOI: 10.5897/IJPS11.1604.

Shariati, A., *et al.* (2012b), "Various types of shear connectors in composite structures: A review", *Int. J. Phys. Sci*., **7**(22), 2876-2890.

Shariati, A., *et al.* (2014a), "Experimental assessment of angle shear connectors under monotonic and fully reversed cyclic loading in high strength concrete", *Constr. Build. Mater.*, **52**, 276-283. https://doi.org/10.1016/j.conbuildmat.2013.11.036.

Shariati, M. (2008), Assessment of Building Using None-destructive Test Techniques (ultra Sonic Pulse Velocity and Schmidt Rebound Hammer), Universiti Putra Malaysia.

Shariati, M., *et al.* (2013), "Comparison of behaviour between channel and angle shear connectors under monotonic and fully reversed cyclic loading", *Constr. Build. Mater.*, **38**, 582-593.

Shariati, M. (2013), Behaviour of C-shaped Shear Connectors in Stell Concrete Composite Beams, Jabatan Kejuruteraan Awam, Fakulti Kejuruteraan, Universiti Malaya.

Shariati, M., *et al.* (2012b), "Fatigue energy dissipation and failure analysis of channel shear connector embedded in the lightweight aggregate concrete in composite bridge girders", *Proceedings of the 5th International Conference on Engineering Failure Analysis*, 1-4 July 2012, Hilton Hotel, The Hague, The Netherlands.

Shariati, M., *et al.* (2010), "Experimental and analytical study on channel shear connectors in light weight aggregate concrete", *Proceedings of the 4th International Conference on Steel & Composite Structures*, 21 - 23 July, 2010, Sydney, Australia.

Shariati, M., *et al.* (2012c), "Experimental assessment of channel shear connectors under monotonic and fully reversed cyclic loading in high strength concrete", *Mater. Design*, **34**, 325-331. https://doi.org/10.1016/j.matdes.2011.08.008.

Shariati, M., *et al.* (2011a), "Shear resistance of channel shear connectors in plain, reinforced and lightweight concrete", *Scientific Res. Essays*, **6**(4), 977-983. DOI: 10.5897/SRE10.1120.

Shariati, M., *et al.* (2011b), "Experimental and numerical investigations of channel shear connectors in high strength concrete", *Proceedings of the 2011 World Congress on Advances in Structural Engineering and Mechanics (ASEM'11+)*, Seoul, South Korea.

Shariati, M., *et al.* (2015), "Behavior of V-shaped angle shear connectors: experimental and parametric study", *Mater. Struct.*, 1-18. https://doi.org/10.1617/s11527-015-0762-8.

Shariati, M., *et al.* (2016), "Comparative performance of channel and angle shear connectors in high strength concrete composites: An experimental study", *Constr. Build. Mater.*, **120**, 382-392. https://doi.org/10.1016/j.conbuildmat.2016.05.102.

Shariati, M., *et al.* (2011c), "Behavior of channel shear connectors in normal and light weight aggregate concrete (Experimental and Analytical Study)", *Adv. Mater. Res.*, **168**, 2303-2307. https://doi.org/10.4028/www.scientific.net/AMR.168-170.2303.

Shariati, M., *et al.* (2012e), "Behaviour of C-shaped angle shear connectors under monotonic and fully reversed cyclic loading: An experimental study", *Mater. Design*, **41**, 67-73. https://doi.org/10.1016/j.matdes.2012.04.039.

Shariati, M., *et al.* (2014b), "Fatigue energy dissipation and failure analysis of angle shear connectors embedded in high strength concrete", *Eng. Fail. Anal.*, **41**, 124-134. https://doi.org/10.1016/j.engfailanal.2014.02.017.

Shariati, M., *et al.* (2017), "Assessment of stiffened angle shear connector under monotonic and fully reversed cyclic loading",. *Proceedings of the 5th International Conference on Advances in Civil, Structural and Mechanical Engineering - CSM 2017*, Zurich, Switzerland.

Shariati, M., *et al*. (2019b), "Moment-rotation estimation of steel rack connection using extreme learning machine", *Steel Compos. Struct.*, **31**(5), 427-435. https://doi.org/10.12989/scs.2019.31.5.427.

Shi, X., Hassanzadeh-Aghdam, M.K. and Ansari, R. (2019a), "Viscoelastic analysis of silica nanoparticle-polymer nanocomposites", *Compos. Part B: Eng.*, **158**, 169-178.

Shi, X., Jaryani, P., Amiri, A., Rahimi, A. and Malekshah, E.H.(2019b), "Heat transfer and nanofluid flow of free convection in a quarter cylinder channel considering nanoparticle shape effect", *Powder Technology*, **346**, 160-170.

Siddique, R. and Naik, T.R. (2004), "Properties of concrete containing scrap-tire rubber–an overview", *Waste Management*, **24**(6), 563-569. https://doi.org/10.1016/j.wasman.2004.01.006.

Sinaei, H., *et al.* (2011), "Numerical investigation on exterior reinforced concrete Beam-Column joint strengthened by composite fiber reinforced polymer (CFRP)", *Int. J. Phys. Sci.*, **6**(28), 6572-6579.

Sinaei, H., *et al.* (2012), "Evaluation of reinforced concrete beam behaviour using finite element analysis by ABAQUS", *Scientific Res. Essays*, **7**(21), 2002-2009.

Skripkiūnas, G., *et al.* (2010), "Porosity and durability of rubberized concrete", *Proceedings of the 2nd International Conference on sustainable construction materials and technologies*.

Son, K. S., *et al.* (2011), "Strength and deformability of waste tyre rubber-filled reinforced concrete columns", *Constr. Build. Mater.*, **25**(1), 218-226. https://doi.org/10.1016/j.conbuildmat.2010.06.035.

Tahmasbi, F., *et al.* (2016), "Shear capacity of C-shaped and L-shaped angle shear connectors", *PLoS One*, **11**(8), e0156989.

Tai, V.V., *et al.* (2017), "Modified genetic algorithm-based clustering for probability density functions", *J. Stat. Comput. Simul.*, **87**(10), 1964-1979.

Talsania, S., *et al.* (2015), "A review of pervious concrete by using various industrial waste materials", *J. Int. Acad. Res. Multidisciplinary*, **2**(12), 142-151.

Thang, L.D., *et al.* (2016), "A new design approach based on differential evolution algorithm for geometric optimization of magnetorheological brakes", *Smart Mater. Struct.*, **25**(12).

Thomas, B.S., *et al.* (2016), "Abrasion resistance of sustainable green concrete containing waste tire rubber particles", *Constr. Build. Mater.*, **124**, 906-909. https://doi.org/10.1016/j.conbuildmat.2016.07.110.

Toghroli, A. (2015), Applications of the ANFIS and LR models in the prediction of shear connection in composite beams/Ali Toghroli, University of Malaya.

Toghroli, A., *et al.* (2018a), "Evaluation of the parameters affecting the Schmidt rebound hammer reading using ANFIS method", *Comput Concret*, **21**(5), 525-530. https://doi.org/10.12989/cac.2018.21.5.525.

Toghroli, A., *et al.* (2014), "Prediction of shear capacity of channel shear connectors using the ANFIS model", *Steel Compos. Struct.*, **17**(5), 623-639. http://dx.doi.org/10.12989/scs.2014.17.5.623.

Toghroli, A., *et al.* (2017), "Investigation on composite polymer and silica fume -rubber aggregate pervious concrete", *Proceedings of the 5th International Conference on Advances in Civil, Structural and Mechanical Engineering - CSM 2017*, Zurich, Switzerland.

Toghroli, A., *et al.* (2016), "Potential of soft computing approach for evaluating the factors affecting the capacity of steel - concrete composite beam", *J. Intell. Manufact.*, 1-9.

Toghroli, A., *et al.* (2017), "Investigation on composite polymer and silica fume–rubber aggregate pervious concrete", *Proceedings of the 5th International Conference on Advances in Civil, Structural and Mechanical Engineering - CSM 2017*, Zurich, Switzerland.

Toghroli, A., *et al.* (2018b), "A review on pavement porous concrete using recycled waste materials", *Smart Struct. Syst.*, **22**(4), 433-440. https://doi.org/10.12989/sss.2018.22.4.433.

Trung, N.T., *et al.* (2019), "Moment-rotation prediction of precast beam-to-column connections using extreme learning machine", *Struct. Eng. Mech.*, **70**(5), 639-647. https://doi.org/10.12989/sem.2019.70.5.639.

Trung, N.T., *et al.* (2019), "Reduction of cement consumption by producing smart green concretes with natural zeolites", *Smart Struct. Syst.*, **24**(3), 415-425. https://doi.org/10.12989/sss.2019.24.3.415.

Vo-Duy, T., *et al.* (2017), "A global numerical approach for lightweight design optimization of laminated composite plates subjected to frequency constraints", *Compos. Struct*., **159**, 646-655. https://doi.org/10.1016/j.compstruct.2016.09.059.

Wang, Q., *et al.* (2019), "Analysis on thermal hydraulic performance of the elliptical tube in the finned-tube heat exchanger by new method", *Int. J. Heat Mass Transfer*, **134**, 388-397.

Warudkar, A. and Valekar, N. (2015), "A technical and economical assessment of replacement of coarse aggregate by waste tyre rubber in construction", *Int. J. Recent and Innovation Trends in Computing and Communication*.

Xie, Q., *et al.* (2019), "An experimental study on the effect of CFRP on behavior of reinforce concrete beam column connections", *Steel Compos. Struct*., **30**(5), 433-441. https://doi.org/10.12989/scs.2019.30.5.433.

Xu, C., *et al.* (2019), "Using genetic algorithms method for the paramount design of reinforced concrete structures", *Struct. Eng. Mech*., **71**(5), 503-513. https://doi.org/10.12989/sem.2019.71.5.503.

Xue, J. and Shinozuka, M. (2013), "Rubberized concrete: A green structural material with enhanced energy-dissipation capability", *Constr. Build. Mater*., **42**, 196-204. https://doi.org/10.1016/j.conbuildmat.2013.01.005.

Yang, J. and Jiang, G. (2003), "Experimental study on properties of pervious concrete pavement materials", *Cement Concrete Res*., **33**(3), 381-386. https://doi.org/10.1016/S0008-8846(02)00966-3.

Zhang, Z., *et al.* (2017), "Influence of crushing index on properties of recycled aggregates pervious concrete", *Constr. Build. Mater*., **135**, 112-118. https://doi.org/10.1016/j.conbuildmat.2016.12.203.

Ziaei-Nia, A., *et al.* (2018), "Dynamic mix design optimization of high-performance concrete", *Steel Compos. Struct*., **29**(1), 67-75. https://doi.org/10.12989/scs.2018.29.1.067.

CC

Acronyms

SF= Silica fume (SF)

PC= Pervious concrete (PC)

PCPs= PC pavements (PCPs)

CR= crumb rubber (CR)

TC=tire chips (TC)

UPV= Ultrasonic Pulse Velocity

RN= Rebound Number

DMOE= Dynamic Modulus of Elasticity

RCR= Roller-compacted Rubbercrete

CRC= Cement-Rubber Composite

ACRC= Arated Cement-Rubber Composite

F-T= Freeze Thaw