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THE RUBBERIZED MODIFIED CONCRETE BEHAVIOR UNDER STATIC LOADING

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ABSTRACT

Application of elastomers in concrete industry has been successful in the last few years perhaps due to some properties of these substances, which make it possible for the elastomers such as rubber aggregates to save the tougher cementitious compounds. This paper investigates the mechanical properties and fracture toughness of rubberized modified concrete under static loading. The natural aggregate was replaced partially with different rubber contents of (5-10-15-20-25-30-40 %) replacement of fine rubber aggregate with size of (1-4)mm, and contents of (5-15-25 %) as a replacement of coarse rubber aggregates with size of (4-20)mm. Laboratory tests include compression and indirect tension were conducted, static flexural test was carried out using square slab specimens. The results from laboratory testing on all concrete specimens were analyzed. It was found that the inclusion of rubber aggregates into concrete will reduce the strength of concrete. The usage of fine aggregate sizes of rubber up to specified dosage, gives better strength of concrete compared that of greater sizes of rubber aggregates.The rubberized modified concrete can absorb fracture energy and has more suitable usage in roads, bridges, airports runways and some of the military defensive constructions such as shelters and fortifications.

1. Introduction

The concrete industry generally is one of the major consumers of natural resources all over the world, according to DubravkaBjegovic et al. (2011) [1], the normal concrete (NC) industry spends yearly 1.5 billion tons of cement, 900 million liters of water and 9 billion tons of sand and different types and sizes of stones.

Recently, many efforts were made in order to replace non-renewable resources with renewable one without significant effect on concrete mechanical properties. The principles of Green Buildings have penetrated the construction industry at an accelerating rate in recent decades. Whereas the idea of using recycled materials in concrete production was widely unknown only a few years ago.The different types and shapes of these materials such as the elastomeric products have been an

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integral part of everyday products and are indispensable in the concrete industrial sector [2].

In numerous research studies for the rubberized modified concrete (RMC), different waste materials were used depending on properties needed from composite. Furthermore, the rubber of recycled tyres which can be considered the most famous polymeric wastes because of rubbers exhibiting in a broad range of demanded physical and mechanical properties, represents a main environmental issue that's because of about 1000 million tyres reach the end of their useful lives. At present huge numbers of tyres are already stockpiled or landfilled, about 300 million in the US only and 180 million inside EU. The number of tyres from vehicles is expect to reach 1200 million should to be discarded or recycled in a regular basis -representing almost 5000 million tyres- for their serious environmental threats by the year 2030 (F. Pacheco Torgal et al. 2012) [3].

According to Bala Muhammad et al. [4], polymers and elastomers with different types are being increasingly used in the civil engineering applications as modifiers of concrete materials, especially for the purpose of improving the physical, mechanical, and durability properties of NC [5]. The rubber powder is used as important additive to bituminous mixtures since 1930. It has been used as a part of totally fine aggregate to improve certain properties, and permanent deformation of concrete mixtures, the other reason for using rubber in the concrete mixes is to reduce the pollution and construction material costs [6]. Consequently, RMC has become a matter of interest in the last few years, due to its low density, high ductility, and good performance and as an alternative for tyre recycling. This type of elastomeric material provides a good mechanical behavior under static and dynamic actions, they are proposed other uses for architectural and building applications [7, 8].

The investigations development of recycled rubber and concrete production methods have made it possible to produce RMC with much higher ductility. In general, it can be observed the reduction of compressive strength and split tensile strength of RMC, while its toughness and ability to absorb fracture energy were enhanced significantly. So, the enhanced toughness can easily reduce the resulting damage on concrete elements which resulted from the static loads. On the other hand, the responses and behaviors of RMC elements that may be subjected to static loads explored extensively for both civil and different military applications such as defensive constructions. Studying and analyzing the behavior of concrete that exposed to static loads is necessary, whereas several failure modes and crack pattern observed by many investigations. Therefore, special precautionary design measures may be necessary for this type of concrete.

According to Jusli et al. (2015) [9], the rubber tyre particles were obtained from the mechanical shredding of waste tyre rubber done with two sizes of particles (smaller than 1mm to 4mm) for fine aggregates, and (from 4mm to 15mm) for coarse aggregates, and those sizes used as partial replacement of the fine and coarse aggregates, respectively in the RMC [10]. Moreover, the rubber aggregate (RA) is used in many investigations as fine size to minimize the loss in mechanical properties and to show a better performance with average strength reduction if compared to the reduction of strength in concrete that mixed with coarser size [11, 12]. Most of researches concluded the reduction of concrete compressive strength -which is considered the most important of the mechanical properties of rubberized concrete and influences on many other different properties- ranging from 10% to 70% relative to the increase of (RA) percentage in the mixture [13].

States (2011) [14] concluded the proportional relation between the tensile strength of RMC and the compressive strength which decrease with RA replacement percentage increase. As Antil (2014) [15] defined the flexural strength or the modulus of rupture for RMC as an indirect measure of the tensile strength and he concluded also the reduction of flexural strength with the increase of RAproportion in concrete. Furthermore, it is reported by manyresearchers that, flexural strength of RMC is lower than the natural aggregates concrete, which can sustain load more than the rubberized concrete [16, 17].

In this research project, the main goal is to investigate the behavior of rubberized concrete using different percentages for two sizes of rubber as partial aggregates replacement. For all different RMC mixtures, tests include compression, indirect tension were conducted and the flexural test was carried out to evaluate the tested specimens' response towards the static loading.

2. Experimental Setup

An experimental program was planned and carried out to investigate the effect of sizes and different percentages of RA contents, on the mechanical properties of the hardened concrete (Compressive strength, indirect tensile strength and flexural strength). The behavior of the tested slabs under static loading was reported to come up with information about the absorbed energy and the crack pattern.

2.1. Materials Properties

All test specimens were fabricated using locally available materials. The main characteristics of the mix are: ordinary Portland cement (CEM I 52.5N), coarse aggregate dolomite with maximum aggregate size of 14mm and specific gravity of 2.6, natural siliceous sand with specific gravity of 2.55 and the used dosage of superplasticizer was determined to achieve 70±10mm slump and was obtained by using the (Sikament-NN) as a highrange waterreducing admixture, complies with ASTM C494 type F. For flexural specimens,the ordinary reinforcement consisted of 10mm-diameter deformed bars (steel grade 500, fy/fu=36/52) placed in two directions.

Fig. 1.Sizes of the used RA (fine & coarse).

Two sizes of RA are used in this research and obtained from mechanical shredding for the wasted tyre by "Arabian Company for Recycle Rubber and Refurbished Rubber Manufacturing". As shown in Fig.1, the first size is from 1mm to 4mm for the fine rubber aggregates (FRA) and the second is from 4mm to 14mm for coarse rubber aggregate (CRA), those sizes are used as partially replacement of sand and dolomite, respectively in RMC. The grading of fine and coarse natural and rubberized aggregate are presented in table 1.

Table 1.Grading of natural and rubberized aggregate.

Sieve, mm		20	14	10	5	2.36	1.18	0.6	0.3	0.15
Passing	Sand	100	100	100	98	94	76	37	22	8
	(FRA)	100	100	100	92	65	38	13	9	2
	Dolomite	100	96	40	3	0	0	0	0	0
	(CRA)	100	91	35	5	0	0	0	0	0

The used rubber was treated with washing by water and was dried enough before using, to assure better cohesion of rubber aggregates with cement paste. According to technical support department of this company, some of the chemical compositions for the recycled rubber are presented in table 2. The replacement percentages are determined by volume for natural aggregates content.

Table 2.Chemical compositions of waste tyre.

Constituent	Results %
Natural rubber	15
Synthetic rubber	26
Fillers (carbon black, silica, carbon chalk)	29
Fabric, antioxidant, accelerators, antizionants	17
Plasticizer (oils and resins)	10
Ash content	2
Vulcanization, zinc oxide, various chemicals.	1

2.2. Experimental Program

The experimental program included preparation and testing of fresh concretes and development of several mechanical properties of hardened concrete such as compressive strength, indirect tension, flexural strength.

2.2.1. Studied parameters

This research studies mainly the effect of using different contents & sizes of RA as partially replacement for the natural aggregates on behavior of concrete towards the static loading. The phases and parameters considered to study this effect are adding 5-10-15-20-25-30-40 % of fine rubber aggregate (FRA) and 5-15-25% of coarse rubber aggregate (CRA) as partially replacement for sand and dolomite respectively. All of concrete mixes proportions were designed by the absolute volume method, control mix proportions that measured by weight was cement: 400Kg/m³, sand: 710Kg/m³, dolomite: 1065Kg/m³, water: 0.4 by weight of the cement and super-plasticizer). Whereas, the equivalent weight of fine and coarse rubber aggregate replacement is calculated as volumetric percentage of natural aggregates (sand and dolomite) respectively, as mentioned in equations (1) and (2). All mixes proportions were mixed together in a concrete mixer with capacity of about $0.1m^3$. The coarse aggregate (dolomite/coarse rubber), fine aggregate (sand/fine rubber) and cement were mixed in dry state for about one minute. Mixing water and super plasticizer were added gradually to the dry mixed materials during the next two minutes.

Fig. 2.Set-up of the flexural tests.

$$FR._{eq} = S * (g_{FR}/ g_s) \qquad (1)$$

$$CR._{eq} = D* (g_{CR} / g_d) \qquad (2)$$

Where:

$FR._{eq}$=Equivalent weight of FRA in kg.

$CR._{eq}$=Equivalent weight of CRA in kg.

S = Weight of natural fine aggregates (sand) in kg.

D= Weight of natural coarse aggregates (dolomite) in kg.

g_{FR},g_{CR},g_s and g_d are specific weights for FRA, CRA, sand and dolomite, respectively.

2.2.2. Evaluating tests

The fluid concrete was placed into the moulds. Specimens used in this experimental work consisted of cubes 100x100x100mm for compression test, cylinders100mm diameter and 200mm height for indirect tension test and reinforced slabs with 500x500mm dimensions and 60mm thickness for the central flexural load tests. The net cover of the steel reinforcement was 10mm and the spacing of bars was 150mm in both directions.

After 24 hours the specimens were de-moulded and water cured in controlled conditions for 28 days. All specimens were cast and treated under the same environmental conditions.

Compression test was carried out according to the Egyptian Code No. 203 [18].Moreover, the indirect tension test was carried out according to BS standard [19], using 1000kN universal testing machine, those tests were performed after 28 days. As shown in Fig2, the static flexural test was performed under concentrated load on specimens, whose size was 500x500x60mm as tested by EL Safoury(2015) [20].

Special preparation was done for the 100kN universal testing machine to be suitable for testing slabs as illustrated in Fig.2, using steel frame of 400mm clear span rested on the bed of testing machine. Also , a hard steel ball of 30 mm diameter was provided to the loading head of the testing machine in order to apply a central concentrated point load.This test was used to measure the flexural capacity of slabs, the deflection of tested slabs was measured by dial gage.

3. Experimental Results

The mean of three tested values that have been performedon the trial mixes at 28 days was recorded to determine the compressive, splitting tensile and flexural strength for all mixtures.

3.1. Compressive and splitting tensile strength

The mean values of measured compressive strength and splitting tensile strength for different plain concrete, fine rubber aggregate concrete (FRAC) and coarse rubber aggregate concrete (CRAC) are presented in table 3.

Moreover, the ratios of the compressive and tensile strengths losses relative to the strengths value of control concrete mixture at 28 days of the age, were calculated and presented also in the same table, to evaluate the influence of rubber aggregate size and percentage on concrete mechanical properties.

3.1.1. Compressive strength

The effect of partial replacement percentages of the used FRA in RMC mixtures on the compressive strength (f_{cu}) results after 28 days is presented in Fig.3. Whereas the relation between the partial replacement percentages of the used CRA, the mean values of f_{cu} is shown in Fig.4.

Replacement of natural aggregates with percentages of different rubber aggregates (fine or coarse) influences negatively on concrete f_{cu}, this reduction is ranging from 2% to 53% according to the increase of RA percentage in the mixture and the size of RA as well.

Results in Fig.3, which evaluate the relation between percentages of FRA and compressive strength f_{cu} in (MPa) are showing that: compressive strength is reduced from 41.3 to 28.6MPa according to the increase of FRA percentage from 0% to 40% respectively, this reduction is around 31%. As shown in Fig.3, the losses in FRAC compressive strengths f_{cu} is less than the reduction which is due to the replacement of dolomite by CRA, this loss is around 53% resulted from CRA replacement of 25%.

Table 3. Compressive and tensile strengths results for control and (RMC) mixtures.

Concrete type	Control	Fine rubberized aggregates concrete (FRAC) %							Coarse rubberized aggregates concrete (CRAC) %		
		5	10	15	20	25	30	40	5	15	25
f_{cu}, MPa	41.3	40.5	38.7	38	36.5	35.8	32.4	28.6	32.1	28.8	19.4
Loss % of f_{cu}	0	2%	6%	8%	12%	13%	22%	31%	22%	30%	53%
f_{sp}, MPa	3.83	3.73	3.67	3.57	3.34	3.27	2.78	2.66	3.35	2.88	2.23
Loss % of f_{sp}	0	3%	4%	7%	13%	15%	27%	31%	13%	25%	42%

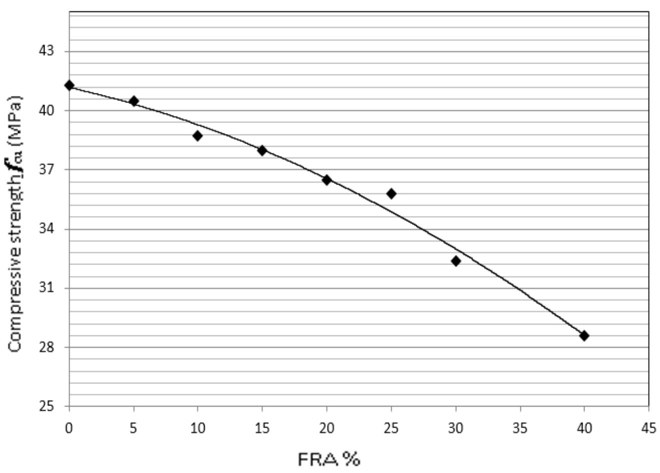

Fig. 3. Relation between FRA percentages and compressive strength.

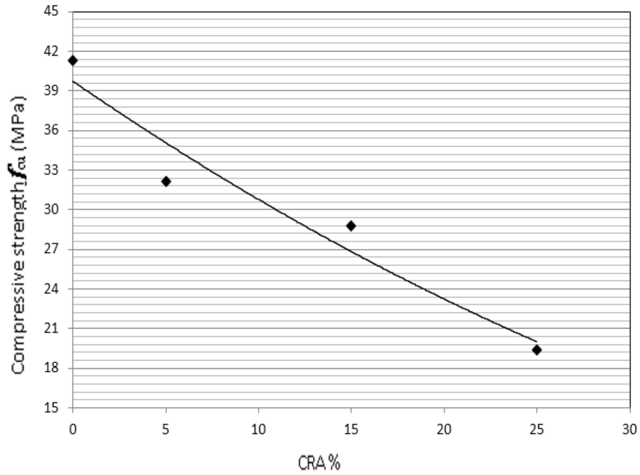

Fig. 4. Relation between CRA percentages and compressive strength.

As presented in Fig.5, f_{cu} of natural aggregates concrete (NC) is 41.3MPa, this value influenced negatively and decreased to be 19.4MPa -less than the half of NC f_{cu} value when partial volume replacement of dolomite by CRA percentage increases to 25%. This reduction decreases in the case of replacing the same percentage of sand by FRA and FRAC f_{cu} of 25% replacement is 35.8MPa, which means that the reduction is about 13%. Furthermore, the FRAC and CRAC f_{cu} of 5% replacement is 40.5MPa and 32.1MPa respectively.

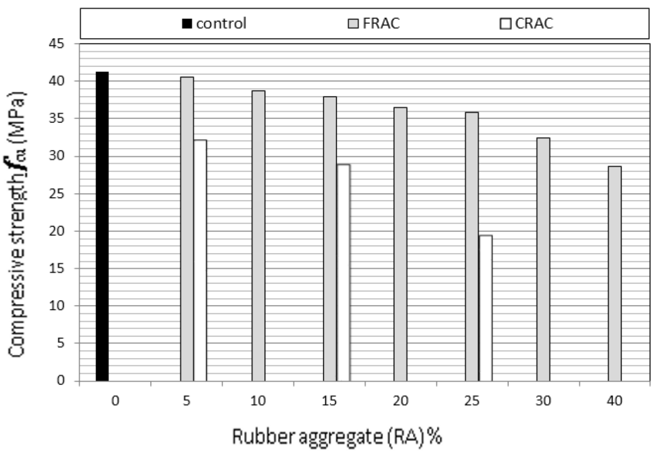

Fig. 5. Rubber aggregates size and percentages effect on compressive strength.

In addition, the FRAC and CRAC f_{cu} of 15% replacement is 38MPa and 28.8MPa, which means about 8% and 30% losses in compressive strength respectively. Generally, the presence of rubber aggregates with different percentages and sizes affects negatively on f_{cu} of the rubberized concrete, the relation between the reduction in compressive strength and the rubber aggregate percentage was found to be nonlinear.

Many of possible explanations can be suggested in this investigation for the compressive strength losses. One of those explanations is the fact that the different sizes of RA act as voids in the cement matrix because of the lower specific gravity of the rubber aggregate if it is compared to the cement paste. Moreover, the low strength of RA relative to strength of the natural aggregates. The increase of air pores that formed around RA in the hardened RMC matrix participate in the reduction of compressive strength. Furthermore, this losses influenced by the lack of adhesion and the weak bond between RA and the cement paste, That leads to easier cracks growth around RA during the loading which accelerates the failure of tested cube under the compression load, and the size of replaced RA is considered one of most effective parameters influences the compressive strength of RMC.

For instance it is noticed that, in the case of replacing the dolomite of different percentages with CRA, the value of compressive strength loss is much more than the compressive strength losses of concrete mixed with same percentages of FRA replacement, and this conclusion agreed with many investigation [21, 1]. However, this conclusion contradicts M. Mavroulidou et al. (2010), as it was found that for the same percentage of RA, the CRAC had higher $\boldsymbol{f}_{cu}$ than concrete containing the finer RA [22].

3.1.2. Splitting tensile strength

As the same behavior of RMC towards the compressive strength, the replacement of natural aggregates with different percentages of RA leads to direct reduction of the concrete splitting tensile strength (f_{sp}) as presented in Table 3, that reduction is ranging from 3% to 42% according to the size of RA, and its percentage increase in the mixture.

The presented results in Fig.6,which evaluates the relation between percentages of FRA and f_{sp}, shows that, f_{sp} is reduced from 3.83 to 2.66MPa according to the increase of FRA percentage from 0%to 40% respectively, this reduction is around 31%.On the other hand, the losses of f_{sp} which resulted because of the partial replacement for sand is less than the reduction which is due to the replacement of dolomite with CRA which is around 42% as shown in Fig.7, even if this comparison is between the percentages of 40% and 25% only for FRAC and CRAC respectively.

As presented in Fig.8,$f_{sp}$of NC is 3.83MPa, this value decreased to 2.23MPa which is considered about 42% of f_{sp} reduction when partial volume replacement of dolomite by CRA percentage increases up to 25% of the total volume. This losses in f_{sp} decreases in the case of replacing the same percentage of FRA by sand, and f_{sp} of FRAC of 25% replacement is 3.27MPa, which means that the reduction is about 15% only.

On the other hand, the loss in f_{sp} decreases proportionally with reduction of RA replacement percentage due to the variable size effect. For example, FRAC and CRAC f_{sp} of 5% replacement is 3.73MPa and 3.35MPa meaning a reduction of about 3% and 13%, respectively.

Also, FRAC and CRAC f_{sp} of 15% replacement is 3.57MPa and 2.88MPa, which means around 7% and 25%

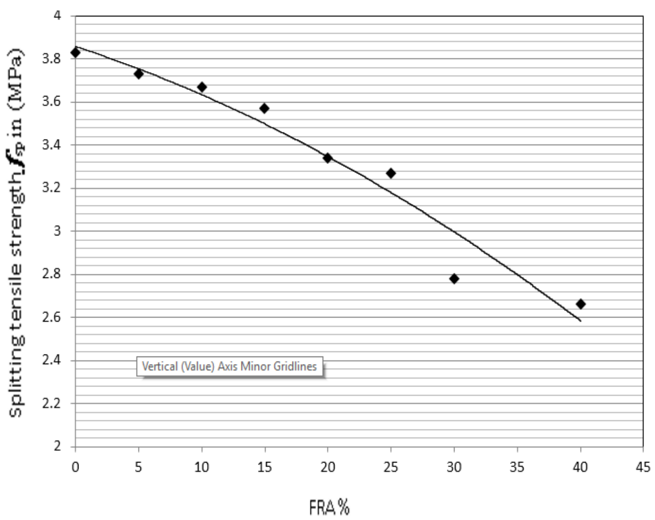

Fig. 6. Relation between FRA percentages and splitting tensile strength.

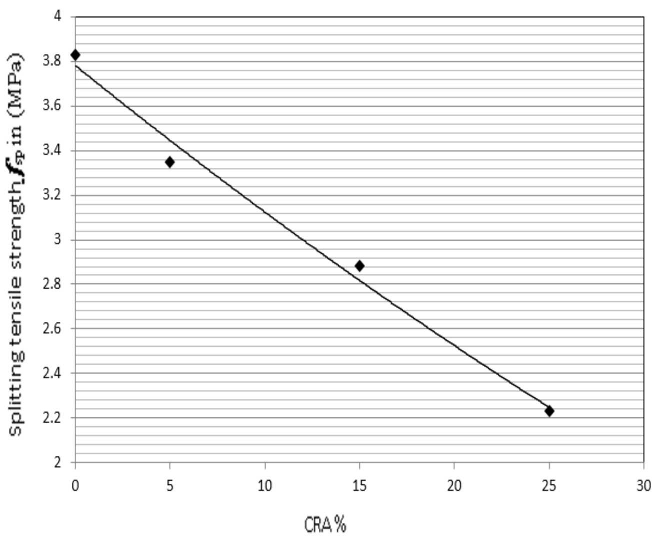

Fig. 7. Relation between CRA percentages and splitting tensile strength.

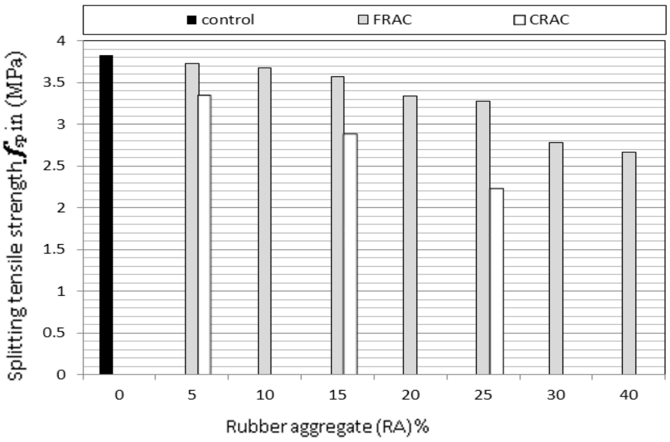

Fig.8. Rubber aggregates size and percentages effect on splitting tensile strength.

Losses in f_{sp}, respectively. It is noticed that , the slight effect of RA replacement in decreasing the tensile strength may be due to the same reasons mentioned in the previous section.

Different sizes of RA presented as voids in the concrete mixture. So, the losses in the tensile strength may be because of this type of aggregates which reduces the gross cross section of the concrete element. In addition, the bond between RA and the cement paste is considered weak, and the lower strength of RA has a negative significant effect on the splitting tensile strength of RMC.

In general, the presence of RA in the concrete mixtures causes a reduction of its splitting tensile strength, but in CRAC when replacing the dolomite with CRA, this reduction is clearly observed lower than the loss of compressive strength of the same concrete mixture as tabulated in table 3.

Whereas, for both NC and FRAC, it was cleared that the amount of FRA up to 20% of sand replacement, influences slightly negatively on the propagation of crack which lead finally to failure. This conclusion is agreed with most of previous investigations[13, 14].

3.2. Static flexural behavior of RMC

The behavior of different concrete mixtures under static flexural loading which was carried out on NC, FRAC and CRAC slabs with different percentages of replacement by FRA and CRA was investigated. The ultimate load and deflection just beneath the point of load application were measured after 28 days. Flexural toughness, crack pattern and modes of failure were also observed. The following sections present and discuss the results of this test.

3.2.1. Ultimate load

For control and different rubberized concrete mixtures, it is observed a marginal effect on the flexural ultimate load (FUL) is resulted from partial replacement percentages of FRA up to 20%. In general, this effect increases clearly if FRA replaced by CRA with the same percentages. As shown in Figs.9 and 10, it can be noticed the direct inverse relation between the percentages of FRA and static ultimate load, whereas CRA percentages have inverse parabolic relation.

In General, the flexural strength of RMC is lower than the normal concrete. FUL for NC is 45.4KN. But it is observed, the maximum flexural load for RMC is 44.1KN for a 5% replacement of FRA, while the minimum strength is 38.3KN reported for 40% replacement for the same size of FRA.

On the other hand, this loss in FUL increases for the same percentages of CRA replacement, as it is reported the flexural load for 5% of CRA replacement is 39.5KN and this value presents a loss of about 13%, which is more than the loss of the same percentage of FRA replacement around 10% in the comparison to the value of FUL for NC. Furthermore, the increase in the CRA replacement percentage leads to more loss in the FUL than the same percentage of FRA replacement, as the losses is 17% and 11% for the 25% replacement of CRA and FRA respectively, those percentages can evaluate how RA size influences on the flexural ultimate load.

As shown in Fig.10, presence of RA with different percentages and sizes affects negatively on the static ultimate load of RMC. But it is observed the slightly reduction results in the case of replacing FRA up to 20% - less than 9% reduction- and the losses in ultimate load increase relatively with RA size increase. However, these losses are much smaller compared to other properties. The reverse relations between reduction of FUL and RA percentage was found to be nonlinear.

some researcher such as Soni [23] reported a slight increase in the values of FUL, and also they concluded the

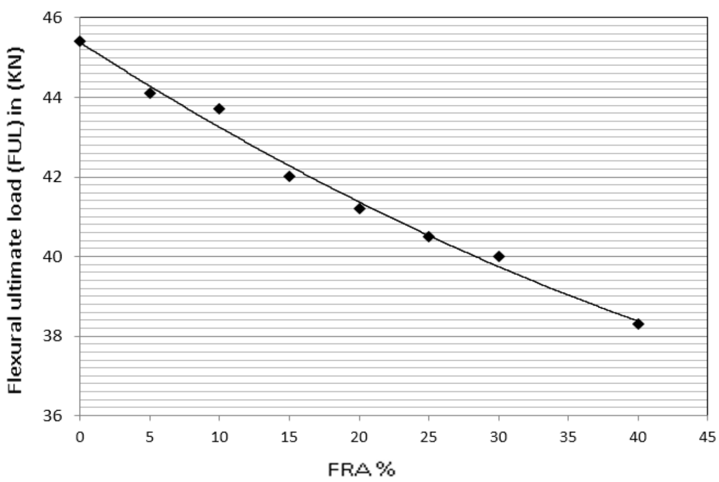

Fig. 9. Relation between percentages of FRA and FUL.

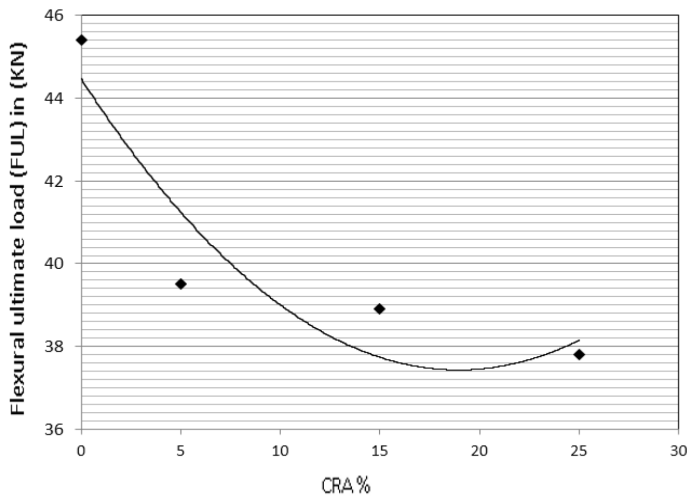

Fig. 10. Relation between percentages of CRA and FUL.

Generally, RMC is softer than NC that is based on rubber material characteristics. For instance, RA is considered as voids in concrete mixture because of its lower specific gravity and strength if it is compared to the natural aggregates. Due to the increase in voids and weaker bonding as rubber percentages increase, RMC slabs show early failure as a result of the low tensile strength in comparison to NC. Therefore, the reduction in FUL can be related to the same parameters influences on the concrete compressive or and the tensile strength.

Furthermore, RA act on delaying or limiting the width of existing cracks moreover that are propagated due to the continuous flexural load and prevent partially the formation of micro cracks by stress relaxation. Consequently, the fracture occurs when the generated cracks break and overcome the bond between cement paste and RA, and the ability of concrete to resist externally applied loads that NC can sustain is limited.

That conclusion is acceptable by many researches and agreed with Abusharar[16], who related the reduction of

flexural strength for RMC to the low modulus of elasticity of RA with respect to natural aggregates. On contrary, peak of this increase resulted from the replacement of about 15% of conventional natural aggregates with FRA.

3.2.2. Load – deflection behavior

For NC, load–deflection relationship seems to be linear during increasing the load from 0 up to about 10kN, and then this relation is transferred to have non uniform trend up to 45.4kN due to the failure of the specimen subjected to ultimate load as illustrated in Fig.11. The central deflection value was about 0.83mm when the applied load was 10kN, while this value increased to be 3.97mm at the ultimate load (failure of the specimen).

Theoretically, this behavior towards the flexural load is logic for NC, and agreed with many previous investigations because in the steel bar reinforced concrete, as the crushing of concrete follows the yielding of steel reinforcement under the increasing of flexural load. The specimen has a conventional ductile flexural mode of failure [17, 20].

The relations between applied load and central deflection in Fig.11, for different FRA replacement percentages are non uniform trend up to the failure load relative to the percentage of replaced rubber, but these results indicated, and it was around 4.2mm. On the other hand, it must be referred to the effect of ultimate load on the evaluation of RMC deflection, although the central deflection was approximate for all FRAC specimens, but it is noticed a clear difference in the ultimate load of failure for all FRAC mixtures.

on the deflection as cleared in FRA partially replacement percentage of 40% which has a central deflection of about 49% compared to the deflection of control mix. In addition, RA size has a slight effect on the central deflection of the tested slabs with the same replacement

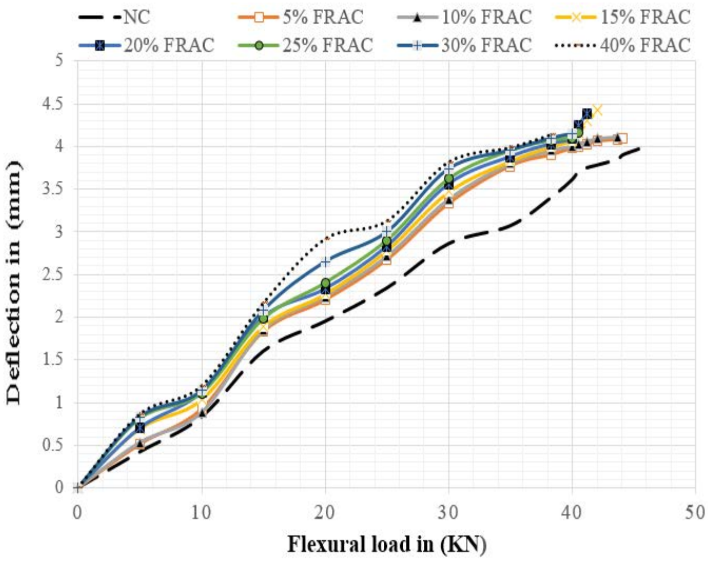

Fig. 11. Deflection-load relation for NC and FRAC(percentage effect of RA).

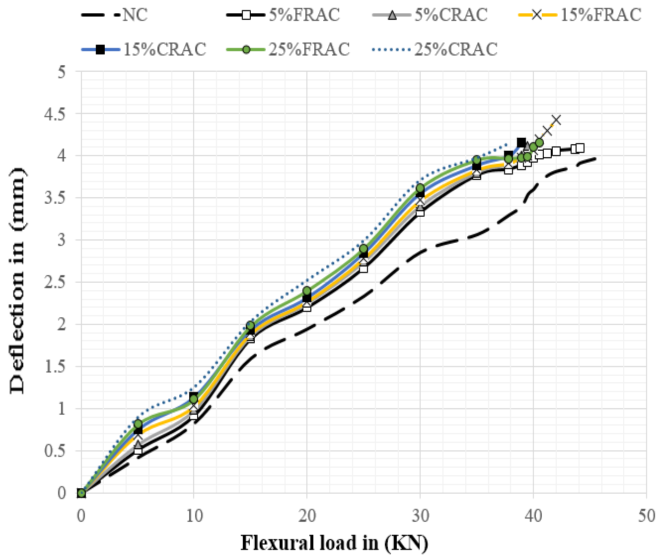

Fig. 12. Deflection-load relation for NC, FRA and CRA (size effect of RA).

The relations between applied load and central deflection in Fig.12, for the same FRA and CRA replacement percentages are non uniform trend up to the failure load relative to the size and percentage of replaced rubber, but a slight increase in the load of failure is observed in CRAC tested slab, if it is compared to FRAC for the same percentage of 5%, that primarily indicated to the positive influence of increasing the size of RA in RMC central deflection relative to the flexural load.

As the same for the rubber replacement percentages evaluation in Fig.11,the values of final central deflection under FUL may not illustrate the influence of adding RA to the concrete mixture. This relates to the failure of RMC slabs which might fracture at a lower load in comparison to CN, therefore final central deflection is smaller.

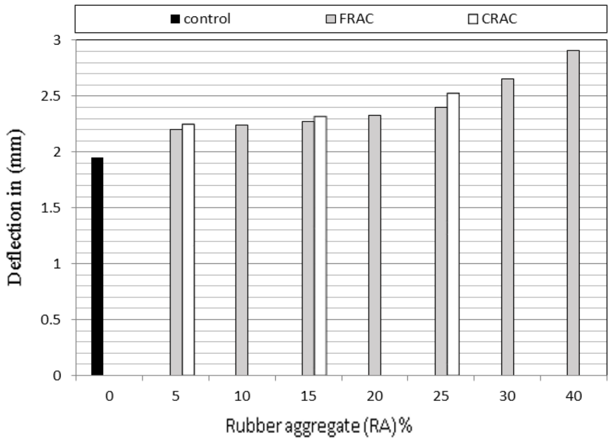

Fig.13. Effect of RA size and percentages on the central deflection under 20KN (50% of FUL).

Fig.13, indicates the central deflection at the 50% of FUL, the increase of RA is generally influences positively

percentages. For example, the increase of about 2% is observed in CRA replacement instead of FRA with the same percentage of 5%, this difference in deflection value

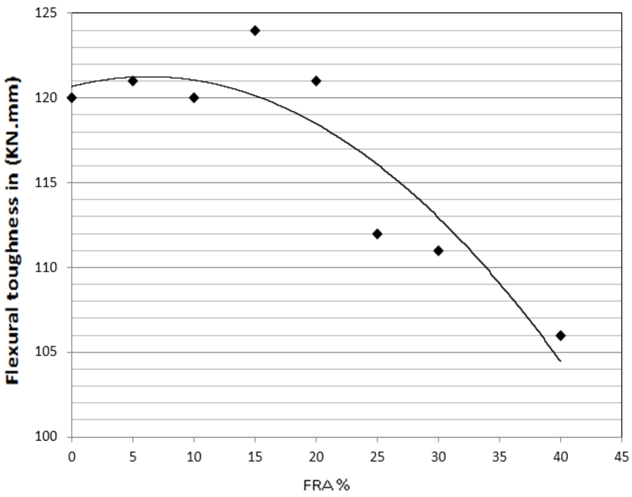

Fig. 14. Relation between percentages of FRA and flexural toughness.

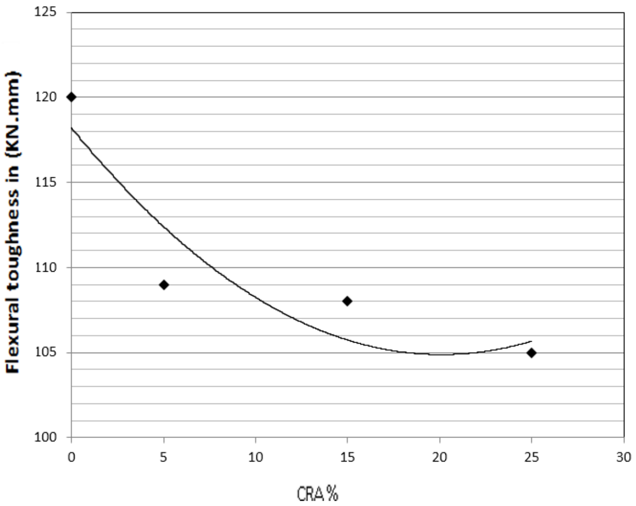

Fig. 15. Relation between percentages of CRA and flexural toughness.

is noticed to be increased relative to the replacement percentage, as it reach 5% for CRA replacement percentage of 25% more than central deflection of FRA replacement with the same percentage, in a clear indication to the more flexibility of CRAC than FRAC and NC.

Moreover, RMF slabs exhibited a clear increase in the central deflection in comparison to that of NC at 50% of FUL. The final deflection observed at failure for the different percentages of FRAC and CRAC, did not show a similar increase due to the difference in ultimate load if it is compared to NC failure ultimate load value, or even the more percentage of RA replacement.

Therefore it can be concluded that, this increment is proportionally with the increase of FUL. This conclusion coincide with Hussein (2011) [24], where he found the increase in final deflection at failure cannot be attributed only to an increase in flexibility, but it also may be as a result of an increased in first-crack load, which allowed the tested specimen to reach a higher deflection.

3.2.3. Flexural toughness

The replacement of natural aggregates with the FRA

has a slight positive effect up to the replacement percentage of 20%, the peak of the enhancement is about 3% in comparison to NC is obtained in a partial replacement of 15% as shown in Fig.14. Conversely, the increase of FRA replacement percentage more than 20% leads to direct reduction in flexural toughness and that reduction is ranging from6% to 12% for FRA percentages of 25% and 40% respectively, and this reduction is expected to be proportional with the increase of FRA percentage in the mixture.

The illustrated results in Fig.15, evaluate the relation between increasing the CRA replacement percentages in comparison to NC and flexural toughness values. Furthermore, flexural toughness is reduced from 109KN.mm to 105KN.mm according to increasing CRA percentage from 5% to 15% respectively, this reduction is around 9% and 13% respectively relative to NC flexural toughness.

The size of used RA has significant effect on the values of concrete flexural toughness, as presented in Fig.16, this effect when replacing the 25% of natural aggregates by CRA which has less toughness than NC (about 13%). This percentage is equivalent nearly more than twice of flexural toughness value -which is 6% - for the same FRA replacement percentage of 25%. By this result, it is indicated clearly to the negative effect of RA size on concrete toughness. On the other hand, the flexural toughness for FRAC in comparison to NC enhanced slightly with the increase of FRA replacement percentage up to 20%, the peak of this influence -which is 3%- is gained by replacing 15% of FRA. More than this replacement percentage slight reduction of the flexural toughness is observed proportionally with FRA replacement percentages.

Toughness can be defined as energy absorption capacity of a material equivalent to area under flexural load versus the deflection curve which illustrates the resulting deformation from that load. So, RMC toughness response evaluates the energy absorption that represents ductility of this type of concrete and its resistance to the impact loads which is presented later.In this investigation, FRAC mixtures up to 20% replacement percentage are known for their high toughness, having a high energy absorption capacity when compared to NC.

As discussed earlier, the best result for all toughness values is for 15% replacement, due to significant enhancements in strain capacity and energy absorption, which are presented clearly in the deflection increase. The enhancement of flexural toughness of FRAC can be explained also by the ability of FRA to absorb more energy before the fracture of the tested specimen when compared to the concrete matrix and that is because of the rubber aggregates' bending and twisting properties which are not existing in sand.

In addition, there is no aggregate bridging found in the case of FRAC due to the small size of the fine rubber. However, it may be occurred in the case of CRA. This conclusion agreed with some authors who reported that, FRA can increase a few toughening mechanisms to the concrete mixture such as the crack bridging [3, 25].

Conversely, adding CRA with different replacement percentages lead to the reduction in the energy absorption capacity of RMC, because of the direct positive relation between the strength of dolomite and fracture response of concrete. Furthermore, the decrease in flexural toughness of CRAC and the high range of FRAC replacement percentages (more than 20%) may be attributed to the lower ultimate flexural strength compared to that of NC, as Hussein confirmed [24].

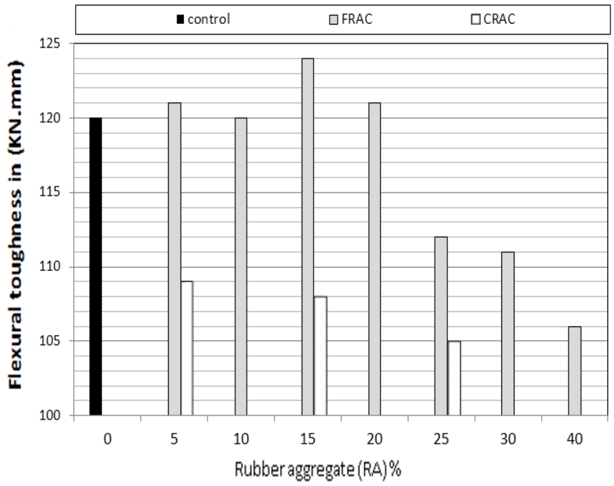

Fig. 16.Effect of RA size and percentages on concrete flexural toughness.

3.2.4. Modes of failure

Figs. from 17 to 27, illustrate the mode of failure and cracking pattern for the tested FRAC, CRAC and NC slab specimens. It was cleared that the size and proportion of RA in concrete mixture moreover the FUL influence on the crack pattern and the mode of failure for the tested slabs. Comparing the cracking behavior for all tested slabs indicates to the decrease of crack width relative to the increase of RA replacement percentages for the two tested sizes FRA and CRA.

Generally, the failure takes place rapidly in (RMF). But, for FRA replacement, there is no particle bridging and that causes a little effect to delay the crack propagation more than CRA replacement [26]. Whereas, FRA up to the replacement percentage of 25%, is shown to prevent partially the formation of microcracks by the stress relaxation.

Therefore, fracture occurs when the generated cracks are capable of overcoming the bond between cement paste and RA, and the ability of RMC to resist externally applied flexural load which NC can sustain is limited after 20% FRA replacement.

Fig. 17. Fracture mode of NC under flexural load.

Fig. 18. Fracture mode of 5% FRAC under flexural load.

Fig. 19. Fracture mode of 10% FRAC under flexural load.

Fig. 20. Fracture mode of 15% FRAC under flexural load.

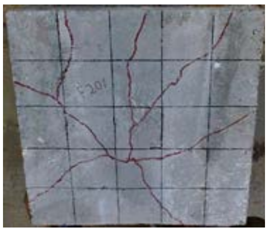

Fig. 21. Fracture mode of 20% FRAC under flexural load.

Fig. 22. Fracture mode of 25% FRAC under flexural load.

Fig. 23. Fracture mode of 30% FRAC under flexural load.

Fig. 24. Fracture mode of 40% FRAC under flexural load.

Fig. 25. Fracture mode of 5% CRAC under flexural load.

Fig. 26. Fracture mode of 15% CRAC under flexural load.

Fig. 27. Fracture mode of 25% CRAC under flexural load.

4. Conclusions

Based on the experimental results presented in this study the following conclusions can be drawn:

1. In general, reduction in concrete compressive and tensile strength relative to replacement percentages of sand or dolomite by fine or coarse rubber aggregates respectively. But the coarse rubber aggregates are more effective in this reduction.
2. Compressive strength decreases by 53% and 13%, at 25% replacement of coarse and fine aggregate respectively.
3. The RA size effect on the tensile strength is less than its effect on compressive strengthreduction, it decreases about 42% and 15% at 25% replacement of coarse and fine aggregate respectively.
4. The presence of fine rubber aggregates in concrete increased the resistance of concrete to the crack initiation under static load. Therefore, toughness of FRAC of (15-20%) is much greater than the control mix because the elastic nature is able to absorb more energy.
5. The FRA had no particle bridging effect, on contrary the CRA. Hence, the mode of failure of RMC under static loading is varied relative to the size of RA.
6. At higher contents of fine rubber aggregate (20-40%) or coarse rubber aggregate concrete, the number and the width of the crack increases which leads to the failure.

Finally, although the compressive strength and tensile strength is low for rubber modified concrete mix with different percentages and sizes. However, it can sustain sufficient load even after crack generation. According to the construction application requirements, adequate percentage of fine rubber can be replaced in concrete mix to obtain good combination of strength and toughness.

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