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Effect of Irradiated Crumb Rubber on Rubberized Concrete Properties

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ABSTRACT
The objective of this paper is to study the effect of irradiation crumb rubber on the mechanical properties of rubberized concrete. An experimental model was carried out on 30 standard cubes to determine how some properties of rubberized concrete affected by the two percents (30% and 70%) of irradiated treated crumb rubber content as a sand replacement. The Scanning Electron Microscopy for irradiated rubber powder, the ultimate compressive strength and nondestructive tests for rubberized concrete with slump, wet and dry densities and absorption tests were performed. The irradiation process was achieved by gamma ray in air medium with a source of Co-60 radiation unit and dose rate 0.3kGy/h with a total absorbed dose of 70kGy. The experimental results had been recorded a noticeable reduction in the ultimate compressive strength of rubberized concrete relative to normal concrete. The reduction percent increases as the rubber content increases. While the tested results indicated a significant improvement in term of ultimate compressive concrete strength with irradiation rubber powder of 30% by weight of sand replacement relative to one without irradiation. This evidence is proved by both destructive and nondestructive tests. The irradiated rubber particle zooming image at Scanning Electron Macroscopy level before mixing with concrete ingredients proved a significantly surface modification. While, the rubberized concrete failure surface at macroscopic level recorded a bond enhancement. The study leads to conclusion it is possible to produce structural rubberized concrete with a irradiated treated rubberized powder and still maintaining the other excellent properties in term of weight and impact resistance.

Keywords: *Rubberized Concrete; Ultimate Compressive Strength; Irradiated Crumb Rubber; Scanning Electron Macroscopy.*

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I. INTRODUCTION

There are a real environmental problems with the disposal of used and waste tires. Solid scrap tires management has become one of the serious problems in environment due to unavailability of large number of disposal places, large space tire void occupies, in addition of fire and diseases hazard. Many research areas were trying to use the huge quantities of waste tires in asphalt mixes and in plastic and rubber manufacturing [1]. Some other researchers are starting to make the rubberized concrete to improve some properties in the concrete [2]. Many experiments were performed to find how the properties of normal concrete changed with the inclusion of waste tire [3]. All previous attempts in this field were recorded that there was a noticeable decrease in the ultimate compressive strength of rubberized concrete relative to normal concrete. These results led to limit of using rubberized concrete in structural application. Even though, rubberized concrete has some advantages relative to normal concrete such as lower density, higher impact and toughness resistance, enhanced ductility and better insulation provider [4, 5, 6, 7]. It is intend in this work to make rubberized concrete of equivalent to normal concrete in term of ultimate compressive strength by pre-treating the rubber powder by irradiation process before mixing it with concrete.

II. SCRAP TIRES AND CRUMB RUBBER

A typical tire weight is ranging from 20 to 100 Ib. Scrap tires can be handled as a whole tire, Silt tire, shredded tires and ground rubber or as a crumb rubber product. In the shredded tire the size of the tire shreds normally from 75 mm to 15 mm [8]. Crumb rubber may be size from 4.75 mm to less than 0.075 mm [9, 10, 11]. In this research, crumb rubber is used in concrete production as a partially sand replacement with two percentage ratios of 30% and 70% of the sand weight required in concrete. The crumb rubber is taken from Al-Najaf tires factory with the composition by weight is given in Table 1.

Table 1: Tiers Composition by Weight

Composition by weight	Al-Najaf Tires	Typical Tires
	Percent weight	Percent weight
Rubber: hydro carbon	48	41
Carbon black	31	28
Acetone extract Ash Residue chemical balance	15 2 4	31

The composition by weight in table above excludes the steel usually embedded with the tires. In general steel contributes from 14 to 15% of the total weight of the any tires. It is trying as possible from the crumb rubber grading analysis to use equivalent percentage passing of the sand and to satisfy the Iraqi specification [12].
Crumb rubber powder has been subjected to radiation with gamma ray to increase its particles surface bound activity during the reactions with other concrete constitutes. The irradiation has been done in air medium. A source of Co-60 radiation unit with dose rate 0.3kGy/h and a total absorbed dose of 70kGy have been implemented in this study.

CONCRETE MATERIALS AND PREPARATION

The concrete constituents and the mixture design is greatly affected the quality of the concrete. The raw materials used in performance of the experiments included the Portland cement, gravel, sand and water with crumb rubber. Sand replacement of 30% and 70% of crumb rubber are used in the percent work.
Ordinary Portland cement manufactured in Iraq is used. This cement complied with the Iraqi specification [13]. The course aggregate maximum size of (19.5) mm is used according to the Iraqi standard [12]. While sand is complying with zone (2) according to the same standard above [12]. 30 standard cubes of side length of 15 cm were made in this investigation. The first trial consists of six cubic which are used as control or base samples were only the normal concrete is used without tire powder. Second trial take into account six cubic which are used with 30% sand replacement by weight with crumb rubber without radiation process. While the third trial of also six specimens with 30% sand replacement by weight with crumb rubber with radiation process. The last 12 cubic is made for 70% sand replacement by weight with same rubber and radiation process as shown in Table 2. The mixing was done according to American standard of testing material [14]. The rubber powder is subjected to radiation process at the physics department Laboratory and the overall experiments are done at the Civil Engineering department Laboratory. Both Laboratories are part of Al-Nahrain University.

Table 2: Batch Specifications

Cube Name	Crumb Rubber %	Radiation Process	Mix Type	Test Name
C0-11, C0-12, C0-13 C0-14, C0-15, C0-16	0	NA	M0	T1
C30-11(NA), C30-12(NA), C30-13(NA) C30-14(NA), C30-15(NA), C30-16(NA)	30	NA	M30	T2
C30-11(A), C30-12(A), C30-13(A) C30-14(A), C30-15(A), C30-16(A)	30	Applicable	M30	T3
C70-11(NA), C70-12(NA), C70-13(NA) C70-14(NA), C70-15(NA), C70-16(NA)	70	NA	M70	T4
C70-11(A), C70-12(A), C70-13(A) C70-14(A), C70-15(A), C70-16(A)	70	Applicable	M70	T5

III. BATCH SPECIFICATIONS AND MIX PROPORTION

Both the normal and rubberized concrete mixes are designed according to American standard Code of Practice [14] based on absolute volume method. This method is assumed that the absolute volume of concrete is the sum of the absolute volume of the concrete ingredients as:

Absolute volume $= \frac{C}{G_c} + \frac{S}{G_s} + \frac{R}{G_r} + \frac{G}{G_g} + \frac{W}{1.0} = 1000 \text{ liters}$

where:
C, S, R, G and W= Weight of cement, sand, crumb rubber, gravel and water respectively in
Kilogram per one cubic meter of concrete.
Gc, Gs, Gr, and Gg= Specific weight of cement, sand, crumb rubber and gravel
(3.15, 2.65, 0.95, 2.65) respectively.

The cement and water weights in cubic meter was assumed constant, 350 Kg and 175 Kg respectively. Weight of gravel is taken as 1.5 of the weight of both sand and crumb rubber.

$$G = 1.5(S + R)$$

While the weight of crumb rubber is taken as 30% and 70% of the total weights of sand plus rubber.

$$R = KS$$

where:

$$K = \begin{cases} 0 & \text{if } 0\% \text{ of rubber is used} \\ 0.43 \cdots\cdots & \text{if } 30\% \text{ of rubber is used} \\ 2.33 & \text{if } 70\% \text{ of rubber is used} \end{cases}$$

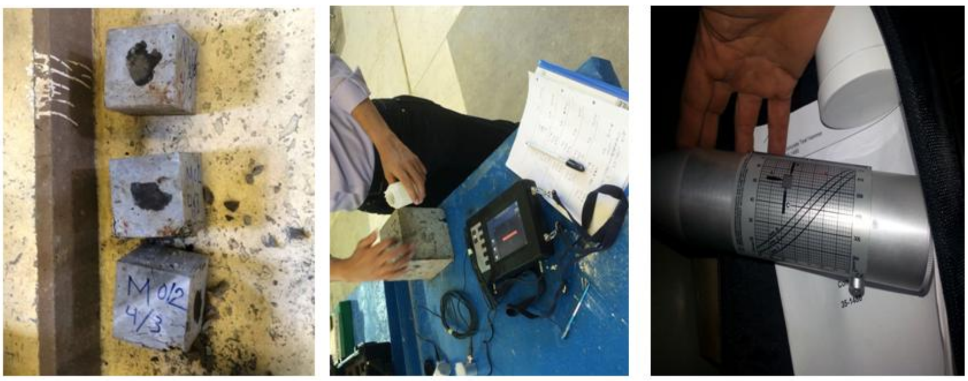
The mixing design results based on above assumption are illustrated in Table 3.

Table 3: Mix Proportion

Mix type	Cement Kg/m3	Sand Kg/m3	Rubber Kg/m3	Gravel Kg/m3	Water tires	W/C
M0	350	757	zero	1135	175	0.5
M30	350	437	188	937	175	0.5
M70	350	152	353	757	175	0.5

IV. TESTING PROCEDURE

There are a series of standardized testing procedures for determining concrete properties. The compressive strength test is carried out according to ASTM C-39-01 [15], using a typical testing machine with a capacity of 2000kN as shown in Fig.1. Ultrasonic pulse velocity test by measuring the pulse transit velocity was done according to ASTM C597-02 [16]. This test is used to give a reference confirmation to the strength of concrete. In addition it may be used as a reference for sound insulation in different concrete batches. Rebound Hammer test is carried out by using Schmidt hammer to estimate the surface hardness of concrete specimens by recording the rebound number, which can be considered as a measure of the concrete strength and percentage of voids. Schmidt hammer type Proceq is used which is shown in Fig.1. The test method is prescribed by ASTM C805-02 [17, 18]. Slump test was also conducted to measure the workability or consistency of concrete. Slump test was performed according to ASTM C143 [19]. While the total absorption test is carried out based on BS 1881 part 122-1989 [20]. The dry and wet densities are measured for all batches using the same tested specimens. Fig.1 shows sample of concrete specimen before and after test, some of laboratory equipment used and finally the crumb rubber adopted in this research.



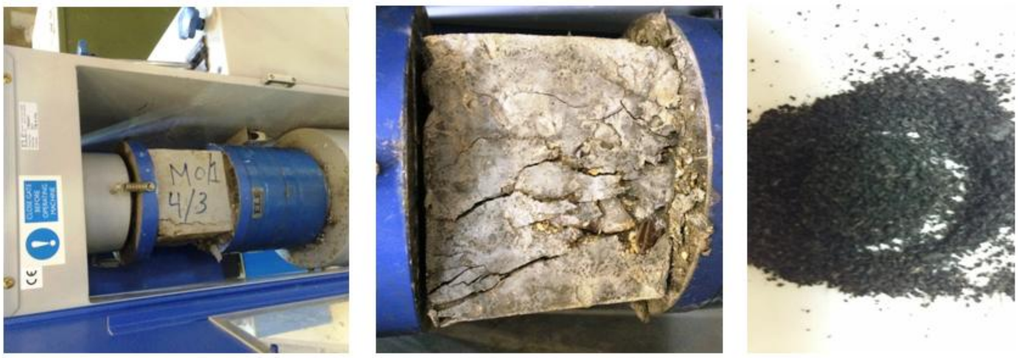
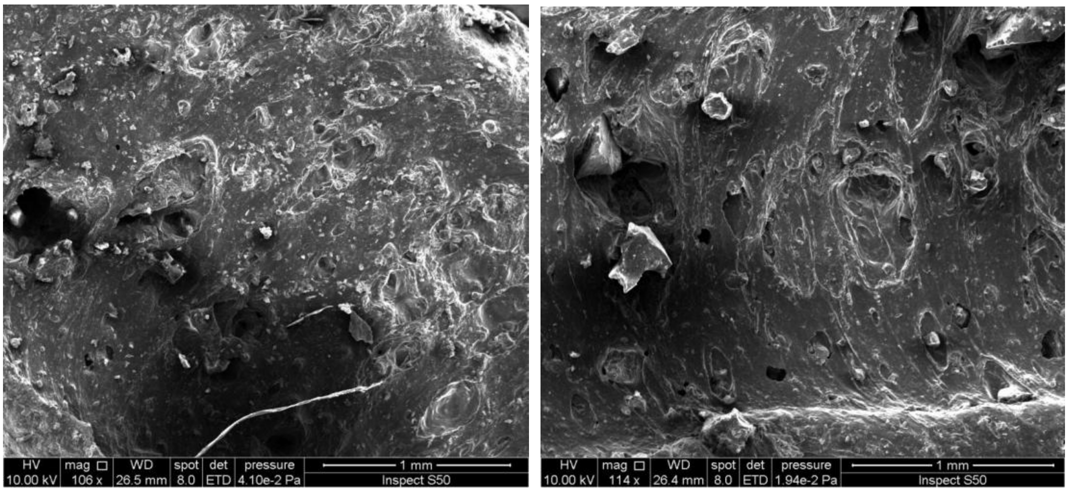


Fig.1: Test Material and Equipments

V. RESULTS AND DISCUSSION

Initially, the Scanning Electron Macroscopy (SEM) images of air un-irradiated and irradiated crumb rubber is carried out and recorded in Fig.2 (a) and (b) respectively. The micrographs of un-irradiated and irradiated crumb rubber particle surfaces showed a noticeable difference in their surfaces. The surface modification of irradiated crumb rubber predicted the bond enhancement with concrete matrix and finally improved the mechanical properties of rubberized concrete. This action of surface modification was attributed to the effects of gamma ray which cause in breaking the chemical bond of the surface of crumb rubber.



(a) **(b)**

Fig.2: Scanning Electron Macroscopy Image. (a) Un-Irradiated Crumb Rubber. (b) Irradiated Crumb Rubber.

Secondly, the experimental results in term of slump value, dry and wet densities and the compressive strength of control concrete specimen (T1) and other specimens (T2 to T5) were recorded in Table 4. Each value in this table represents the average of six samples test results. Figs.3 to 7 show the variation of different concrete property based on two percentage of sand replacement (30% and 70%) by weight with crumb rubber. The irradiated crumb rubber effect was shown in these figures and all these figures were represented with reference to control samples without rubber.

Table 4: Test Results

Test Name	Slump mm	Dry Density Kg/m3	Wet Density Kg/m3	Compressive Strength MPa	Pulse Velocity kM/s	Rebound R	Total Absorption %
T1	100	2400	2500	32	4.50	33.0	4.17
T2	95	1800	2000	18	4.15	23.0	11.11
T3	96	1900	2100	25	4.35	25.0	10.52
T4	90	1650	1750	15	4.05	21.0	6.06
T5	91	1700	1800	20	4.22	22.0	5.10

Workability of the concrete refers to the ability of the concrete to be easily molded. The slum value is one of the important measures for workability of concrete. Fig.3 reports that mortars without crumb rubber (control concrete) achieved workability higher than concrete incorporating rubber. Changing of the un-irradiated rubber with the irradiated one shows the variation in slump was not significant. Because of low specific gravity of crumb rubber particles, unit dry and weight of mixtures containing rubber decreases with the increase in the percentage of rubber content as in Table 4. Fig.4 indicates that the variation of unit weight of rubberized concrete is not a function of rubber irradiation processes.

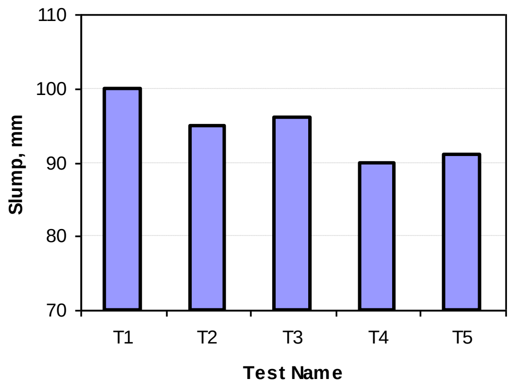


Fig.3: Variation of Slump Values

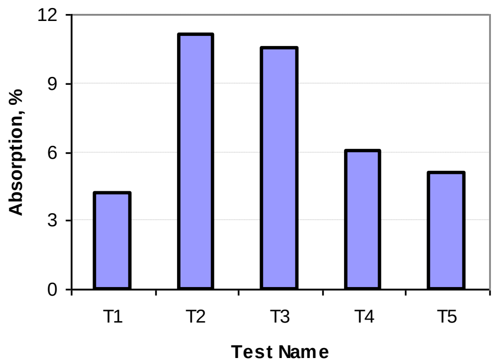


Fig.4: Variation of Absorption Ratios

Compressive strength of rubberized concrete with two percents of crumb rubber subjected to radiation is reported in Fig.5. Results indicate that the compressive strength of un-irradiated rubber concrete is greatly affected by the percentage of crumb rubber sand replacement reference to control sample. There is a significant reduction in compressive strength when un-irradiated crumbs rubber percentage of sand replacement increase as in Table 4. Fig.5 indicates that if the crumb rubber particles have rougher surface (given a pretreatment with radiation), the better and improved bonding may develop with the surrounding matrix, and that result in higher compressive strength.

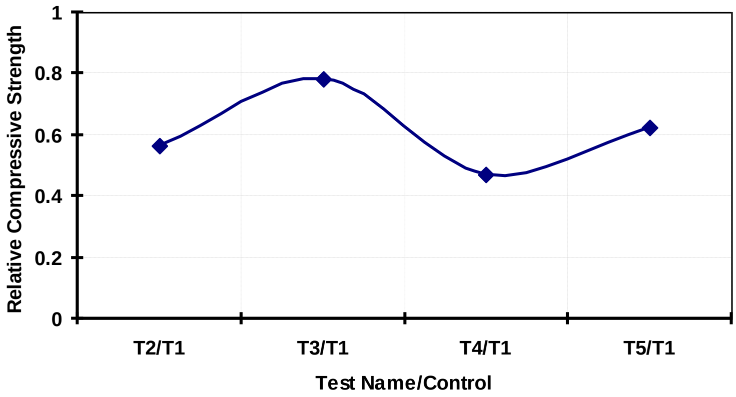


Fig.5: Variation of the Compressive Strength

Fig.6 shows that the ultrasonic pulse velocity of different batches with and without rubber and irradiation treatment. The pulse transit velocity is used to give an indication for sound installation rather than the strength and homogenousity of concrete. Results gives a significant increase in the pulse velocity in using rubberized concrete subjected to radiation compare to one without radiation. Schmidt hammer readings are recorded in Fig.7 for different rubber concrete batches. The readings are used as an indication for impact resistance rather than concrete strength. The result of Hammer test in term of rebound values show higher impact strength when using rubberized concrete than those of normal concrete. Also rebound readings indicate there is no significant variation in its value when using iradiated rubber. In general it is observed that the samples tend to fail more gradually with the addition of crumb rubber. Rubber modified samples are able to undergo a higher deformation than the control mix.

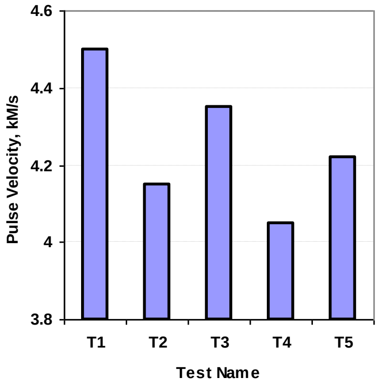


Fig.6: Variation of Pulse Velocity

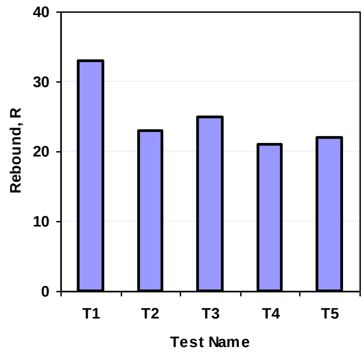


Fig.7: Variation of Rebound

The failure surface of concrete cubic samples has been scanned with Digital Microscope, 200X, and Picture resolution (1600X1200), 0.1 x 0.1 mm original resolution grid. The failure surfaces of rubberized concrete with 70% sand replacement by weight with both un-irradiated and irradiated crumb rubber is shown in Fig.8. The left image represents the rubberized concrete with un-irradiated crumb rubber while the right image represents the irradiated one. Figs.9 showed the rubberized concrete failure surfaces at microscopic level which include crumb rubber without any treatment. While Fig.10 represented the microscopic image of rubberized concrete failure surface with irradiated crumb rubber. It was observed from Fig.9 the rubber particle left huge number of cavity in concrete matrix which indicated the weak bond between the rubber particles and other concrete ingredients. While in Fig.10 small number of holes was observed which led to conclusion that some of rubber particles are cut rather than it is escape from its position and left a cavity.

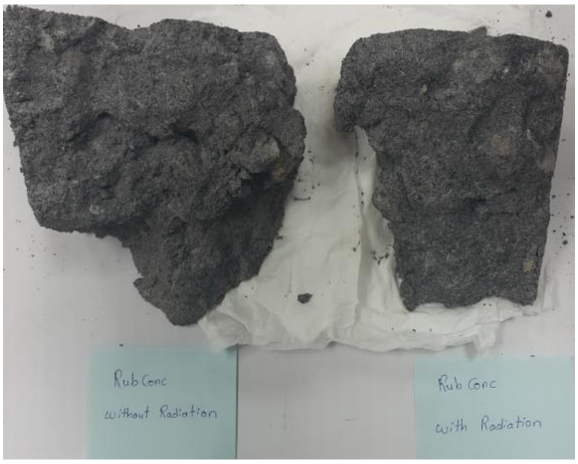


Fig.8: Rubberized Concrete Failure Surface. Left image represents the un-irradiated crumb rubber used while the right image represents the irradiated one

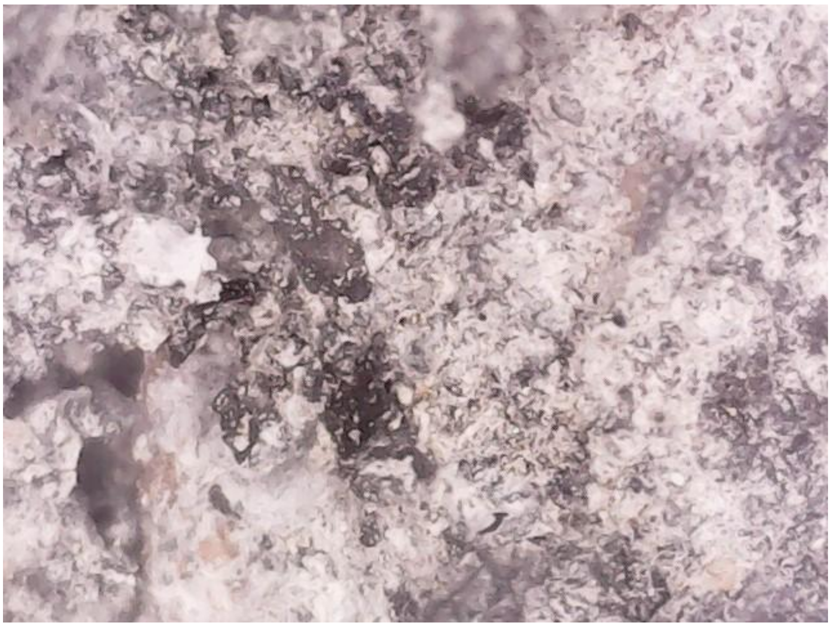


Fig.9: Rubber Concrete Failure Surface without Radiation at Microscope Level

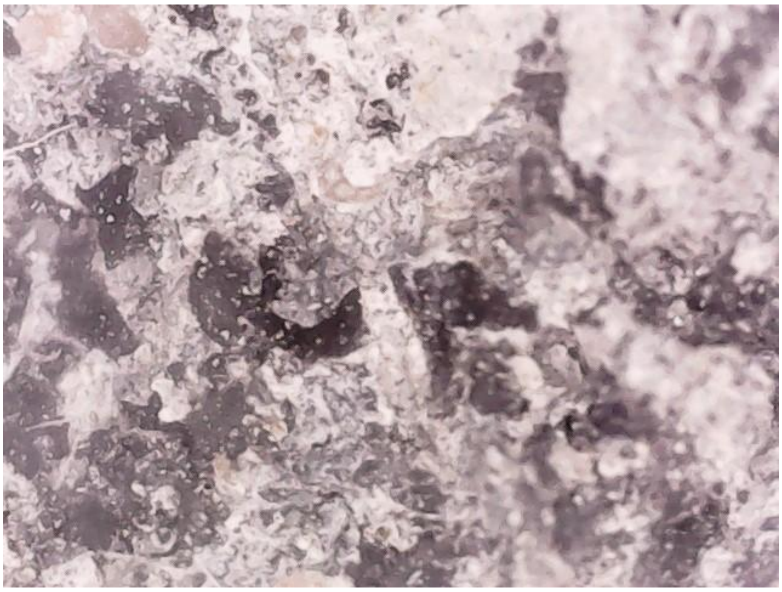


Fig.10: Rubber Concrete Failure Surface with Radiation at Microscope Level

VI. CONCLUSION

1. The micrograph by the Scanning Electron Macroscopy (SEM) for un-irradiated and irradiated crumb rubber particles shows noticeable surface modifications. These observations give an initial indicator for bond enhancement in term of final mechanical properties of rubberized concrete.
2. The compressive strength of rubberized concrete has significant decreases when un-irradiated crumbs rubber percentage of sand replacement increases. But, when the rubberized concrete was used with irradiated crumb rubber it is observed a significant strength improvement. The same results are reached in term of Pulse Velocity test.
3. It is found that the workability, absorption and hammer test results for rubberized concrete is not affected by the radiation of crumb rubber.
4. The number of cavity in the rubberized concrete failure surface with irradiated crumb rubber at microscopic level is small compared to un-irradiated one. It is observed that, when using rubber with radiation, some of rubber particles are cut rather than it is escape from its position and left a cavity). This is a significant indicator for bond enhancement.

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