INFLUENCE OF INTERNAL SULPHATE ATTACK ON SOME OF PROPERTIES FOR CONCRETE CONTAINING RECYCLED AGGREGATE [+]

تأثير التماس الملحي الداخلي على بعض خواص الخرسانة الحاوية على الركام المعاد

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Abstract :

This paper presents a comprehensive experimental study on the resistance of concrete made of partial or full replacement of natural fine and coarse aggregates by recycled aggregates to internal sulphate attach as the main problem in concrete production in Iraq . The replacement and sulphate levels added were the main test variables in this study. The sulphate levels investigated were (0.5 , 1.0 , 2.0 and 2.5%) of fine aggregate weight in addition to that of control sulphate level, while the aggregate replacements levels were (25, 50, 75,and 100%) of those natural fine and coarse aggregates weights. The variations of linear expansion and compressive strength were measured carefully and periodically up to the age of 180 days for both natural and recycled aggregate concretes .

Results indicated that , partial replacement of (75%) level by recycled coarse aggregate or recycled fine aggregate was practically possible without impairing the concrete resistance to sulphate for all SO_3 levels up to (1.0 and 2.0%) respectively at all the ages studied . Full replacement level by one type of recycled aggregate on the (1.0%) SO_3 level was practically possible at all the ages studied . Full replacement level by both types of recycled aggregates must be done in the lower SO_3 levels up to (0.5%) at all the ages studied. Fifty percent replacement level by both recycled aggregates was practically possible for the all ages and SO_3 levels up to (1.0%) .

المستخلص:

في هذا البحث يتم تقديم دراسة موسعة وشاملة حول مقاومة الخرسانة المصنوعة من الركام المعاد المعوض جزئيا أو كليا عن الركام الاعتيادي الناعم والركام الخشن لخاصية التماس الملحي الداخلي باعتبارها أهم المشاكل في صناعة الخرسانة في العراق . إن نسبة الاستبدال ونسبة الأملاح المضافة هي أهم المتغيرات المدروسة في هذا البحث . إن نسبة الأملاح المدروسة كانت (٠,٥ ، ١,٠ ، ٢,٠ و ٢,٥) % من وزن الركام الناعم بالإضافة إلى النسبة المرجعية ، بينما كانت نسبة استبدال الركام المدروسة هي (٢٥ ، ٥٠ ، ٧٥ و ١٠٠) % من الوزن الأصلي للركام الناعم و الخشن . إن نسبة التغيرات الطولية ومقاومة الانضغاط تم دراستها بعناية وبشكل دوري حتى العمر ١٨٠ يوم لكلا النوعين من الخرسانة الطبيعية الركام والمعادة الركام

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أشارت النتائج إلى إمكانية استخدام الركام الخشن المعاد أو الركام الناعم المعاد حتى نسبة (٧٥)% من وزن الركام الطبيعي الأصلي دون الإضرار بأداء الخرسانة لمقاومة التماس الملحي الداخلي على ضوء الخواص المقاسة سابقا وللنسب الملحية المختلفة و لحد (١ و ٢%) على التوالي .وكذلك إمكانية استخدام الركام الخشن أو الركام الناعم بنسبة استبدال (١٠٠%) على ألا تتجاوز النسبة الملحية (١%) ولكافة الأعمار. وبالإمكان استبدال كافة الركام الخشن والناعم ولكافة الأعمار ولنسب ملحية لا تتجاوز (٠,٥ %) . وبالإمكان استبدال نصف الركام الخشن والناعم دون حصل تدهور ملحوظ في هذه المقاومة للأملاح لكافة الأعمار والنسب الملحية إلى الحد (١ %) .

Introduction:

Recently, The availability of demolished waste concrete materials has steadily increased all over the world , and in many cities , there is no locally available aggregate due of the environmental limits which prevent the contaminations from the aggregate plants and the legislation to encourage the use of recycled aggregates. From both , environmental and sustainability points of view , it is important for engineers to ensure effective use of these concrete wastes, and the recycled aggregates offer a promising and reliable outlet to achieve this goal .In practice , successful applications of recycled aggregates in production of concrete have been reported , especially in Denmark , which recycled now , over (80%) of its demolition waste . In UK , demolition waste , and crushed concrete in particular , is being recognized increasingly as a valuable resource .[1]

Physical properties of recycled aggregates play an important role in the mechanical properties of the resulting Recycled Aggregate Concrete(RAC) . The particle shape of recycled aggregate is angular and rough in its surface texture and this leads to more water demand for wetting . It has been reported that for the same workability as measured by slump, there was about (5-15%) increasing in water demand than that of a comparable Natural Aggregate Concrete (NAC) and that , slump loss of (RAC) is faster than that of (NAC)[2]. Vivian W.Y. et.al.[3] proposed an innovative method named " Real-Time Assessment of Water Absorption, RAWA to measure water absorption of recycled aggregate accurately because the traditional method cannot give accurate results , which in turn will give errors in the mix design. The surface of recycled aggregate contains of about (25to60%)contaminated mortar depending on the original strength of the demolished concrete. The amount of adhered mortar resulting from recycled normal strength concrete is lower than that in the case of high strength concrete and increases with the increase of the surface area of aggregate, therefore , adhered mortar increases with the reduction in the maximum aggregate size of the coarse aggregate [4] . For this reason , the relative density of recycled aggregate is less than that of the corresponding natural aggregate . Studies indicated, that a density reduction of about (5%) is occurred in the case of recycled aggregate using and the resulting recycled concrete when compared with those corresponding densities of natural aggregate and the natural aggregate concrete .Water absorption capacity of recycled aggregates are higher than most aggregates in the current use because of its porous surface nature. It is about (5 to6)times and about (12-15) times more than those corresponding in the case of recycled coarse and fine aggregates respectively. The abrasion ratio for natural coarse aggregate is lower than that for a comparable recycled coarse aggregate . Study indicated that the abrasion ratio is raised from about (23%) to about (25- 40%) when the same coarse aggregate is recycled [5] .

Now, British Standards BS 6543: 1985 and Building Research Establishment BRE Digest 433 :1998 [6] [7] classify recycled aggregate into three grades according to their grade of use . The classification is as follows:

1.Lower quality grade use recycled aggregate (ClassRCA1).This grade is originated by using the brickwork debris ,with replacement levels of about (0% to100%) to achieve lower grades of concrete (up to C20, or C35) .

2. Higher quality grade use recycled aggregate (Class RCA2). This grade is originated by using the concrete debris , with replacement levels of about (0% to 20%) to achieve higher grades of concrete (up to grade C50) .

3. Intermediate quality grade use recycled aggregate (Class RCA3). This grade is achieved by using the concrete or brick debris with replacement levels of about (0-50%) Aggregates in Class RCA(2) will be suitable to substitute for Classes RCA(3) and RCA(1) , and RCA(3) for RCA (1).

An alternative way of classifying the recycled aggregates is the density . The materials with an average dry relative density above of (2000or2100) kg/m^3 may be classified as (crushed concrete) . The materials with an average dry relative density of less than (1500) kg/m^3 may be classified as (brick or ceramic) materials. The materials of dry relative density of (1800) kg/m^3 may be classified in between of the previous two types .

Studies related to the engineering properties of concrete incorporating recycled fine or coarse aggregates confirmed that, high quality concrete with recycled aggregate is a realizable goal with the depletion or scarcity of the natural quarries . Development in the aggregate production technologies , and the innovations in the recycling process have led to reliable and enhanced properties of recycled aggregates .Mario Bassan et.al.[8], indicated that, there was a negligible effect occurred in the performance of structural grades of concrete if a blended natural aggregate with recycled one up to 30% was used. They concluded also, that , quality and homogeneity of recycled aggregate are necessary for a high quality concrete , and that using of (100%) of recycled coarse aggregate from precast production waste allows to make "High Strength Recycled Aggregate Concrete ,HSRAC". Lightweight recycled aggregate can be produced successfully by the formulation a mixture of " Ethylene Vinyl Acetate ,EVA." with " Construction and Demolition Waste , CDW" to minimize the loss of strength and elastic modulus of the resulting concrete [9].

Jose studied the influence of replacement level on the porosity of (RAC) . He found that , higher replacement of natural aggregate by recycled aggregate led to a greater pore radius threshold[10]. Deformation and sorptivity of recycled aggregate are of particular concern which will affect the long term durability of building structures [11]. In addition to that , (RAC) has a higher amount of interfacial transition zone (ITZ) as compared with that of (NAC) . This zone will produce a weaker zone in the concrete structure , which will be more vulnerable to the sulphate attack [12,13] .For the previous reasons, recycled aggregate is poorly performed and the studies are focused to improve this area by different methods such as using a method of the "Two Stage Mixing Approach , TSMA" . This a new mixing approach , which helps to form a thin layer of cement slurry on the original surface of the recycled aggregate. This slurry permeates into the porous old cement mortar and fills up the old cracks and voids to reduce the porosity of the recycled aggregate. The adoption of (TSMA) can create an (ITZ) with greater surface area to which the cement mortar can attach , and thus an increased strength of construction structure[14].Another method can be used to improve the quality of (ITZ) by using mineral admixture for (RAC).On this basis , studies suggested that the use of certain amounts of pozzolanic materials such as (silica fume ,slag, or fly ash)into the concrete mixture combined with a multi–stage mixing process enhanced the properties of (RAC)[15]. Studies based on the X- ray diffraction and scanning electron microscopy analyses , found that the formation of gypsum and thaumasite as a result of sulphate attack was significantly contributed to the pronounced deterioration of recycled aggregate concrete [16].

Recycled Aggregate Concrete will suffer of a higher drying shrinkage than that in the most Natural Aggregate Concrete . This is primarily due to the increased quantity of mortar within the concrete as a whole . There is an adhered mortar on the surfaces of recycled aggregate as well as to the additional mortar in the new recycled aggregate concrete[17].

Al- Khafaji J. A.[18], said that , studies on the effect of Internal Sulphate Attack (I.S.A.) in the (NAC) in Iraq indicated , that the allowable limits of sulphate in fine aggregate may be raised to (1.0%) without any destructive effects on the mechanical properties of the concrete . The same conclusion was achieved about the possibility of raising sulphate content in coarse aggregate . Also , studies in the case of concrete containing full or partial replacement by recycled aggregates have been reported , and the results appear to be very promising . More data are , however , required to enhance the confidence in its durable performance. It is necessary to understand the effect of recycled aggregate on the resistance of concrete when exposed to sulphate attack, because , sulphate attack of (RAC) has not been fully established [19].

In this study , attempts to address some of the concerns related to the sulphate resistance of concrete made with partially or fully replacements by recycled fine and coarse aggregates . Tests were selected to investigate and compare the variations in the , linear expansion and compressive strength for the both types of concretes . Internal sulphate attack is a long term function , therefore , tests were done for along period up to the age of (180) days .

Research Significance :

The research is regarded a significant study due to the following reasons:

1.There are serious problems resulting from the increasing amounts of disposal of construction demolition wastes and concrete masses which were used for the security purposes . These concrete productions have been created a severe environmental problem in our country , and they must be treated economically and urgently .

2. The scarcity of natural aggregate of good quality has increased especially for those areas in the middle and south of our country , which lie far away from the adopted quarries. So, there is a real demand for promising alternative sources , such as the recycled aggregates sources which found in these areas themselves to limit the cost resulting from the transportation of aggregate for large distances [9,20].

3. The replacement of natural aggregate by recycled aggregate is done herein as a full replacement instead of fine and coarse aggregate as well as partial replacement .

4. The wide range problem of sulphate in the aggregates in our country may be solved dramatically by these alternative sources .

5. All the materials used here were from Iraqi's sources.

Experimental Work

1. Materials Used

1.1. Cement :

One type of Sulphate Resisting Portland Cement of Kerbela factory was used which was confirmed, with the Iraqi Organization of Standards IOS5_84[21].The chemical physical and mechanical properties of this cement is shown in the Tables (1)A,B,C respectively :

Table (1 A): Chemical Properties of Cement

Oxides	Percentages	Requirements of I.O.S. 5_84
CaO	64.6	-
SiO_2	21.6	-
Al_2O_3	4.2	-
MgO	1.7	≤5
Fe_2O_3	5.1	-
SO_3	2.1	≤2.5
L.O.I	1.5	≤4
Free lime	2.0	≤4
Alkalis(K_2O+ Na_2O)	1.1	
I.R	0.9	≤1.5
L.S.F	0.88	0.66-1.02
Major Compounds	Percentages	Requirements of I.O.S. 5_ 84 %
C3S	49.1	-
C2S	25.0	-
C3A	2.5	≤3.5
C4AF	15.5	-

Table (1 B) : Physical Properties of Cement

Property	Result	Requirements of I.O.S. 5-84
Fineness(Blaine cm_2/gm)	3100	>2300
Soundness (autoclave)%	0.30	<0.8
Setting Time I.S.T(min.) F.S.T(min .)	 120 170	 > 45 <600

Table (1 C) : Mechanical Properties of Cement

Compressive Strength Mpa	Result	Requirements of I.O.S.5-84
3days	16	>15
7days	24	>23

1.2. Natural Fine Aggregate :

Al Akhaidar sand is used in this study as a natural fine aggregate. The grading of the sand is compatible with Zone(2)of fine aggregate grading according to the Iraqi Organization of Standards IOS45-84[22].Tables(2.and 3)illustrate its gradation and some important physical properties respectively. The gradation adopted here was the same , for the recycled fine aggregate .

Table (2):- Gradation of Natural and Recycled Fine Aggregates

Sieve size (mm)	%passing	IOS 45-84 Limits%
4.75	100	90-100
2.36	80	75-100
1.18	64	55-90
0.6	39	35-59
0.3	20	8-30
0.15	1	0-10

Table (3):- Some Important Physical Properties of Natural Fine Aggregate

Property	SSD Bulk Relative Density	Apparent Relative Density	Compacted Unit Weight (kg/m_3)	Sulphate Content %	Absorption Capacity %
Value	2.64	2.67	1750	0.17	2.0

1.3. Natural Coarse Aggregate :

AL-Nebaee rounded aggregate is used in this study with a maximum aggregate size (14)mm. Table (4) shows the gradation of the natural and recycled aggregates which were adopted as the same and conform to the Iraqi Organization of Standards IOS 45-84 .Table (5) explains some additional important physical properties of the natural coarse aggregate.

Table (4) :- Gradation of Natural and Recycled Coarse Aggregates

Sieve size (mm)	%passing	IOS 45-84 Limits%
14	98	95 - 100
10	32	30 - 60
4.75	10	0 – 10
2.36	0	0 - 5

Table (5):- Some Important Physical Properties of Natural Coarse Aggregate

Property	SSD Bulk Relative Density	Apparent Relative Density	Compacted Unit Weight (kg/m_3)	Sulphate Content %	Absorption Capacity %
Value	2.67	2.70	1620	0.07	0.5

1.4. Recycled Fine and Coarse Aggregates :

The recycled aggregate is made after crushing the available concrete debris from the old tested cubes and cylinders found in the laboratory . The strengths of these old tested samples were ranged between (20 to 40) Mpa . The crushing process is carried out into two stages. The first stage was carried out manually to have small to medium sizes of debris and to facilitate the second stage which is used Los-Angelo's machine in crushing the resulting aggregate from the first stage . Los-Angelo's machine rotated of (500) revolutions into two stages, to attain the coarse sizes from the first stage and the fine sizes from the second stage . First stage consisted of (300) revolutions and, (200) revolutions in the second stage were done. The resulting crushed aggregate from the first stage was screened on sieve size (5) mm and the retained portion was sieved on the same standard sieves used in the gradation of coarse aggregate to collect limited weights of crushed coarse aggregate on each sieve . Then , calculated weights of the previous sizes mentioned , were remixed to attain the required gradation mentioned in the previous Table (4) . To collect the required graded recycled fine aggregate mentioned in the Table (2) , the crushed aggregate passing from sieve size (5)mm was re-crushed for the second (200) revolutions in the abrasion machine and screened on the same standard sieves used for the fine aggregate gradation to collect limited weights on each sieve . Calculated weights were remixed to attain the required gradation mentioned .The important physical properties of these recycled aggregates , were measured precisely to make a comparison between these properties for the natural and the corresponding recycled aggregate. Table (6) shows these properties for the two types of recycled aggregates.

Table (6):- Some Important Physical Properties of Recycled Fine and Coarse Aggregates

Property	Bulk Relative Density	Apparent Relative Density	Compacted Unit Weight (kg/m_3)	Sulphate Content %	Absorption Capacity %
Recycled Fine Aggregate	2.30	2.60	1450	0.10	10.0
Recycled Coarse Aggregate	2.40	2.65	1325	0.08	3.5

1.5. Sulphate Lumps :

Naturally occurring sulphate lumps were used in this study to be closer to the occurrence in practice. These lumps were brought from gypsum plants lied in the middle desert road between Al_ Najaf and Kerbela of sulphate content of about of (45)% of their weights. These lumps were crushed , screened and graded on the same standard sieves used for fine aggregate gradation . The resulting sieved and graded lumps were re-mixed with limited weights from each sieve to maintain the required gradation of fine aggregate. Sulphate lumps were added to the natural or recycled fine to achieve the selected sulphate levels of (0.5,1.0,2.0and 2.5)% of the total fine aggregate, regarding that sulphate contents in the original fine aggregate was (0.15%) as an average and (45%) in the lumps . The total weight of fine aggregate was about (643)Kg in the ($1m^3$) fresh concrete mix. The addition process was carried out on the basis of the equation (3.1) below which was derived with the previous limitations mentioned as shown :

$$(0.45Y + 1.5*10^{-3}* 643)/ 643 = X/100 .$$

$$Y= (6.43X-0.96)/0.45 \rightarrow Y\approx 14X - 2.0 \quad \ldots\ldots\ldots\ldots \quad (3.1)$$

where : Y : Weight of sulphate must be added (kg), X : Sulphate level required .

1.6. High Water Reducer Admixture :

Sulphonated Melamine Based Formaldehyde Condensate (SMFC) Super plasticizer of (Melment L10) to enhance the workability of mixtures containing the added sulphate or recycled aggregates or both as well as to enhance the interfacial transition zone of the resulting concrete to be more resistant to sulphate attack. The technical properties as given by the supplier are shown in the Table (7) :

Table (7):- Technical Properties of (SP ML10) as Provided from Supplier

Main Action	Concrete Super plasticizer
Subsidiary Effect	Hardening Accelerator
Appearance	Clear to Slightly Milky Liquid
Solid in Aqueous	20%
Density gm/cm3	1.1
Chloride Content %	Less Than 0.005
PH Value	7-9

1.7. Mixing and Curing Water :

Tap water was used for mixing , and curing throughout this study .

2 . Mix Proportions : Table (8) describes all concrete mixes and their codes used . Symbols were used to be red simply without any conflicts .The overall concrete volume of about (1.2)m^3 was cast to prepare (55) different concrete mixes as denoted in the table. Mixes contained the added sulphate or , and the recycled aggregate were fabricated with the plasticizer mentioned before to avoid the lack in the wetness of the resulting fresh concrete to be within a medium slump of (80-100) mm .Water to cement ratio was adjusted slightly when the plasticizer was used to maintain a rather constant workability . The concrete mixtures were designed to have a target strength of about (45) Mpa .

Table (8):- Mix Proportions of All Mixes Used

Mixture No.	Code	Cement Content kg	Water Content kg	Natural or ,and Recycled Fine Aggregate Content kg	Natural or ,and Recycled Coarse Aggregate Content kg	SP Content kg	Sulphate Weight kg	w/c Ratio
1	NN	450	190	625	1150	-	-	0.42
2	SN0.5	450	165	640	1150	6.75	3.25	0.37
3	SN1.0	450	165	636	1150	6.75	7.25	0.37
4	SN2.0	450	165	630	1150	6.75	13.25	0.37
5	SN2.5	450	165	628	1150	6.75	15.25	0.37
6	25RF	450	165	159R+484N	1150	6.75	-	0.37
7	25RF0.5	450	165	160R+480N	1150	6.75	3.25	0.37
8	25RF1.0	450	165	159R+477N	1150	6.75	7.25	0.37
9	25RF2.0	450	165	158R+472N	1150	6.75	13.25	0.37
10	25RF2.5	450	165	157R+471N	1150	6.75	15.25	0.37
11	50RF	450	165	323R+320N	1150	6.75	-	0.37
12	50RF0.5	450	165	320R+320N	1150	6.75	3.25	0.37
13	50RF1.0	450	165	318R+318N	1150	6.75	7.25	0.37
14	50RF2.0	450	165	315R+315N	1150	6.75	13.25	0.37
15	50RF2.5	450	165	314R+314N	1150	6.75	15.25	0.37
16	75RF	450	165	482R+161N	1150	6.75	-	0.37
17	75RF0.5	450	165	480R+160N	1150	6.75	3.25	0.37
18	75RF1.0	450	165	477R+159N	1150	6.75	7.25	0.37
19	75RF2.0	450	165	472R+158N	1150	6.75	13.25	0.37
20	75RF2.5	450	165	471R+157N	1150	6.75	15.25	0.37
21	100RF	450	165	643R+0N	1150	6.75	-	0.37
22	100RF0.5	450	165	640R+0N	1150	6.75	3.25	0.37
23	100RF1.0	450	165	636R+0N	1150	6.75	7.25	0.37
24	100RF2.0	450	165	630R+0N	1150	6.75	13.25	0.37
25	100RF2.5	450	165	628R+0N	1150	6.75	1525	0.37
26	25RC	450	165	643	288R+862N	6.75	-	0.37
27	25RC0.5	450	165	640	288R+862N	6.75	3.25	0.37
28	25RC1.0	450	165	636	288R+862N	6.75	7.25	0.37
29	25RC2.0	450	165	630	288R+862N	6.75	13.25	0.37
30	25RC2.5	450	165	628	288R+862N	6.75	15.25	0.37
31	50RC	450	165	643	575R+575N	6.75	-	0.37
32	50RC0.5	450	165	640	575R+575N	6.75	3.25	0.37
33	50RC1.0	450	165	636	575R+575N	6.75	7.25	0.37
34	50RC2.0	450	165	630	575R+575N	6.75	13.25	0.37
35	50RC2.5	450	165	628	575R+575N	6.75	15.25	0.37
36	75RC	450	165	643	862R+288N	6.75	-	0.37
37	75RC0.5	450	165	640	862R+288N	6.75	3.25	0.37
38	75RC1.0	450	165	636	862R+288N	6.75	7.25	0.37
39	75RC2.0	450	165	630	862R+288N	6.75	13.25	0.37
40	75RC2.5	450	165	628	862R+288N	6.75	15.25	0.37
41	100RC	450	165	643	1150R+0N	6.75	-	0.37
42	100RC0.5	450	165	640	1150R+0N	6.75	3.25	0.37
43	100RC1.0	450	165	636	1150R+0N	6.75	7.25	0.37
44	100RC2.0	450	165	630	1150R+0N	6.75	13.25	0.37
45	100RC2.5	450	165	628	1150R+0N	6.75	15.25	0.37
46	50RFC	450	165	320R+323N	575R+575N	6.75	-	0.37
47	50RFC0.5	450	165	320R+320N	575R+575N	6.75	3.25	0.37
48	50RFC1.0	450	165	318R+318N	575R+575N	6.75	7.25	0.37
49	50RFC2.0	450	165	315R+315N	575R+575N	6.75	13.25	0.37

50	50RFC2.5	450	165	314R+314N	575R+575N	6.75	15.25	0.37
51	100RFC	450	165	643R+0N	1150R+0N	6.75	-	0.37
52	100RFC0.5	450	165	640R+0N	1150R+0N	6.75	3.25	0.37
53	100RFC1.0	450	165	636R+0N	1150R+0N	6.75	7.25	0.37
54	100RFC2.0	450	165	630R+0N	1150R+0N	6.75	13.25	0.37
55	100RFC2.5	450	165	628R+0N	1150R+0N	6.75	15.25	0.37

Table (9) below explains the meanings of the previous and other symbols used in the study:

Table (3.9) : Symbols Explanation Used in the Study

Sequence	Symbol	Meaning
1	NN	Normal Concrete with Natural Aggregate
2	SN	Super plasticized Concrete with Natural Aggregate
3	RF	Recycled Fine Aggregate Concrete
4	RC	Recycled Coarse Aggregate Concrete
5	RFC	Recycled Fine and Recycled Coarse Aggregates Concrete
6	Right No.	Right Number such as (0.5, 1.0, 2.0, and 2.5)% Represents the Sulphate Content Level by the Weight of Natural or Recycled Fine Aggregate
7	Left No.	Left Number such (25 , 50 , 75, and 100)% Represent the Replacement Level of Natural Aggregate by the Recycled Fine or Coarse Aggregate

3.Mixing , Casting and Testing :

A rotary mixer of about (0.025)m^3 capacity was used for mixing all of the previous concrete mixes . Coarse aggregate were added into two fractions , and the residual finer materials were added between these two fractions to achieve a sandwich like arrangements for the ingredients mixed .The materials were dry mixed till a homogeneity in colors were achieved .In the case of sulphate addition , a calculated weight of grinded and graded lumps were mixed manually and thoroughly, with the pre-weighed fine aggregate to achieve a uniform distribution for these sulphate in the fine aggregate body . Fine aggregate contaminated with sulphate for batch concrete was added on the first fraction of the coarse aggregate . In the case of plasticizer addition , an aqueous plasticizer of (20)% solid material intensity was added at the end of fresh mix achieved, for better results of consistency enhancement. Finally, specimens of prisms shape of (75*75*290)mm for linear expansion test according to the (ASTMC157-93)[23], as well as, cubes of (100*100*100) mm for compressive strength test according to the (BS 1881: Part116- 83) [24] , were cast to be tested at (3) ages, namely (28 , 90 , and 180) days . Each batch concrete mix prepared was of about (0.02) m^3 ,which was enough to cast (9) samples of the required sizes for each test .

Results and Discussion :

1. Linear Expansion Test :

The results of linear expansion are summarized in the Table (10) and the relation between the linear expansion for (NAC and RAC) and sulphate content levels is shown in the Figures (1A,B,C,D,E,and F). The discussion and analysis of these results can be subdivided to be simply monitored as follows:

1.1. Effect of Sulphate Content Levels and Age Variations:_ It can be recognized from the previous mentioned Figures that, linear expansion increases with the increase in SO_3 level and age. Significant increments were recorded on the higher SO_3 level from (1.0% level and up).It has been seen that , expansion was higher for (RC) mixes than that for(RF) mixes at the same age and SO_3 level .

1.2. Effect of Fine Aggregate Replacement Levels Variation: With respect to the fine aggregate replacement levels, a beneficial effect was found for (25RF,50RF,and75RF) mixes , at all the investigated ages .Also , expansion of (25RFand50RF) mixes were closely similar , especially in the lower SO_3 levels up to (1.0%).The recorded data in these replacements levels were lower than those of the corresponding in the (NAC) mixes , indicating to a good performance of these mixes in their resistance to sulphate attack as measured by their expansion. Maximum value of expansion were about (0.5%) for (75RF2.5 mix) at (180) days of age , which was lower of about (40%) than that of the corresponding mix (SN2.5 mix) . Values of about (40and50%) reductions were recorded for the previous mixes at the ages (28and90) days respectively .The enhancement in the performance of these mixes may be attributed to a neutralized effect from the recycled aggregate to sulphate due of its higher porosity [10]. Not all of the sulphate present in concrete may be exposed to the reaction with water, so there is an effective sulphate which is ready for this destructive reaction . The reaction was beneficial at early and later ages due to the limited expansion resulting . Tensile stresses accompanying the previous expansion were lower than the tensile strength of the concrete body , so , it is accommodated from the concrete structure for refinement the physical structure and reduce the porosity of (RAC) mixes without any micro cracks occurrence .

1.3. Effect of Coarse Aggregate Replacement Levels Variation: A thorough inspection of the same previous mentioned Figures reveal that, a significant reduction was recorded of about (40%) for (25RC2.5 mix) as compared with that corresponding (SN2.5 mix) at (28 days) age which increased to about (50%) for (50RC2.5) at the same age. There were about (40%) reductions occurred for the other mixes of (25RCand50RC) at (90) days of age for all SO_3 levels up to (2%) . This beneficial effects were reduced to about (30%) at the age of (180) days. For (25RCand 50RC) mixes , the gain in expansion was about (10_ 40%) , and (0_ 50%) at the age (28) days for the different SO_3 levels . These recorded data varied to about (10-30)% and (10 _ 40)% at the ages of (90 and180) days respectively . This implies that , there was a beneficial effect resulted from coarse aggregate replacement but with a slight decreasing trend with age. There was an adverse effect seen in the case of (50RCand75RC) mixes , especially when SO_3 level raised from (1.0to2.0%) . Their linear expansion began to increase of about (20 to 40 %) for all the investigated ages as compared with those control mixes . This increment was decreased to about (5%) when SO_3 level raised from (2.0to2.5%). This trend was denoted to a better performance of these mixes to sulphate attack on the higher SO_3 levels. This behavior may be attributed to the microstructure nature of (RAC) which was plastic like due of its higher porosity , and mature enough to resist excessive expansion especially at the later ages[14,16].

1.4. Effect of Fine and Coarse Aggregates Replacement Levels variations: A beneficial effect has been seen in the case of both types aggregate replacement as in the mixes of (50RFC) for all sulphate levels at all the investigated ages especially for those (50RFC2.0and 50RFC2.5) . Expansion was closely similar for all ages on the different SO_3 levels up to (1.0%) . At the ages of (28and90) days , expansion was decreased to about (50%) for these two mixes. Linear expansion recorded were the highest for the mixes (100RFC2.0) at (28) days age and up and for those (100RF and 100RC) at (90) days age and up when SO_3 level raised from (1.0to2.5%) . Increments values of about (125 and 200%) than those corresponding of NAC were recorded . The susceptibility of concrete containing recycled coarse aggregate was more than that replaced by fine aggregate ,as reflected by its higher expansion at the same sulphate level and age . In the case of (100RC2.5)mix, some visual disintegration was began to present as cracks at later ages. Some deterioration and disintegration was noted on the mix (100RFC) at all the investigated ages. These remarks were the results of the excessive increases in the resulting expansion. It has been seen that , the uncontrolled expansion occurred at early age of (28) days for all (SO_3) levels up to the level of (2.5%) were recovered at later ages for all mixes (100RFC except for that of 100RFC2.5) .This trend in agreement with the previous trends of (25RF, 25RC,50RF,50RC,75RF,and75RC) reflecting a good performance of (RAC) at later ages . Also, trends indicated that the performance of recycled aggregate concretes was better with the increasing of (SO_3) levels. This may be attributed to the ability of autogeneous healing occurred for the cracks in these mixes [16]. Finally , sulphate attack is a long term destructive function which continues after the age of (28) days and it can be limited by the using of the recycled aggregate concrete .

2. Compressive Strength Test :

Table (10) contains the results of compressive strength test and the Figures(4_2 A,B,C,D,E ,and F) present the variations of this property for (NAC) and (RAC) with the different SO_3 levels and ages investigated . To clarify the effect of these different variables , the discussion and analysis are formulated as follows :

2.1. Effect of Sulphate Content Levels and Age Variations:_ It has been found that compressive strength of (NA and SN) mixes increases with the increase in the age up to(180) days for all SO_3 level up to (1.0%) . Significant decrements were occurred when SO_3 level increased more than (1.0%) up to (2.5%) especially at the later age of (180) days .The behavior of mixes(25RF,50RF, and75RF) , was similar to that of (NA and SN) mixes . It was found that , a beneficial effect was achieved with recycled fine aggregate application especially at later ages. Recycled aggregate improved the trends at these ages by the limiting effect of this destructive action resulting from sulphate rising . Initial drops in strength of about (25%) was occurred as maximum as when the recycled fine aggregate was used for all the ages studied as compared with the control mixes of (NA and SN) .

2.2. Effect of Fine Aggregate Replacement Levels Variation: Mixes of (25RF) shifted the allowable SO_3 level to(2.0%) at the age (90) days for a strength improvement of about (5-10%),and reduced the sharp drop occurred in this strength in the (2.0 and 2.5%) SO_3 level to about (50- 70%) as compared with those corresponding results in (NA and SN) mixes . Also ,the sharp drop in strength was reduced significantly in the previous SO_3 contents for (50RFand75RF) mixes to about (20-40%) . We can see also, that results were closely similar at the all ages of different SO_3 levels up to SO_3 level of (1.0%). The initial strength drops may be attributed to the water absorption of the recycled fine aggregate which ,was about (5) times more than that the corresponding of the natural one as measured an shown in the Table (3.6). Absorption of recycled aggregate thought to be the key factor in strength reduction [17]. Also , reduction in strength may be attributed to the lesser density of (RAC) as compared with that (NAC) . The density of recycled fine aggregate was lower than that for natural one as seen from the tested results shown in Table (6) which is reflected on the density of (RAC) . These reductions were recovered later for some mixes as mentioned before as a result of autogeneous healing and progressive cement hydration .

2.3. Effect of Coarse Aggregate Replacement Levels Variation: Trends of the mixes (25RC,50RC, and75RC) revealed to a similar of those mixes containing recycled fine aggregate, but with lower amounts. There were significant differences noticed between (75RCand75RF) mixes . Control mixes of 25RC recorded a drop in strength less than 25RF of about (5%) as a maximum resulting from recycled coarse aggregate using for all different ages . These drops in strength were recovered later for other mixes .We can see improvements in the recorded strength of about (10and15%) in the case of (0.5%) SO_3 level for (50RCand75RC) mixes respectively for all ages .The improvement was continued for (50RC) mixes of about (10%) for different ages in the case of (1.0%) SO_3 Strength dropped sharply for other SO_3 levels up to (2.5%) .

2.4. Effect of full Replacement level of Fine Aggregate or Coarse Aggregate: Compressive strength increased with the increase in SO_3 level up to (0.5%) for (100RF, and 100RC) mixes of about (15-20%) respectively at all ages as compared with control SO_3 levels . These increments were about (5-10%) continued for (100RF) mixes at the ages of (28and90) days , while drops were recorded for (100RC) mixes of about (5%) when SO_3 level increased to (1.0%) and more at all ages . Compressive strength decreased significantly to values of about (25and30) Mpa for (100RC2.5 and 100RF2.5) respectively at the age of (180) days. Deterioration and disintegration were seen for fully replaced coarse and fine aggregates concretes at the age of (180) days .

2.5. Effect of Fine Aggregate and Coarse Aggregates Replacement Levels variations: The deterioration has been seen on the (100RFC) since the age of (28) days and up . It has been seen that (50RFC) concrete mixes were performed better than those (100RFC) mixes . There were about (10%) increments in strength seen in SO_3 level of (0.5%) . Drop in strengths were occurred of about (10–30%) for (50RFCand 100RFC) mixes respectively for different ages in the higher SO_3 level more than (0.5%) up to (2.5%). Joes [10] thought that , the interfacial transition zone in the resulting (RAC) is more than that in (NAC) , which produced a weaker zone . This area is more vulnerable to the sulphate attack when exposed to severe condition .

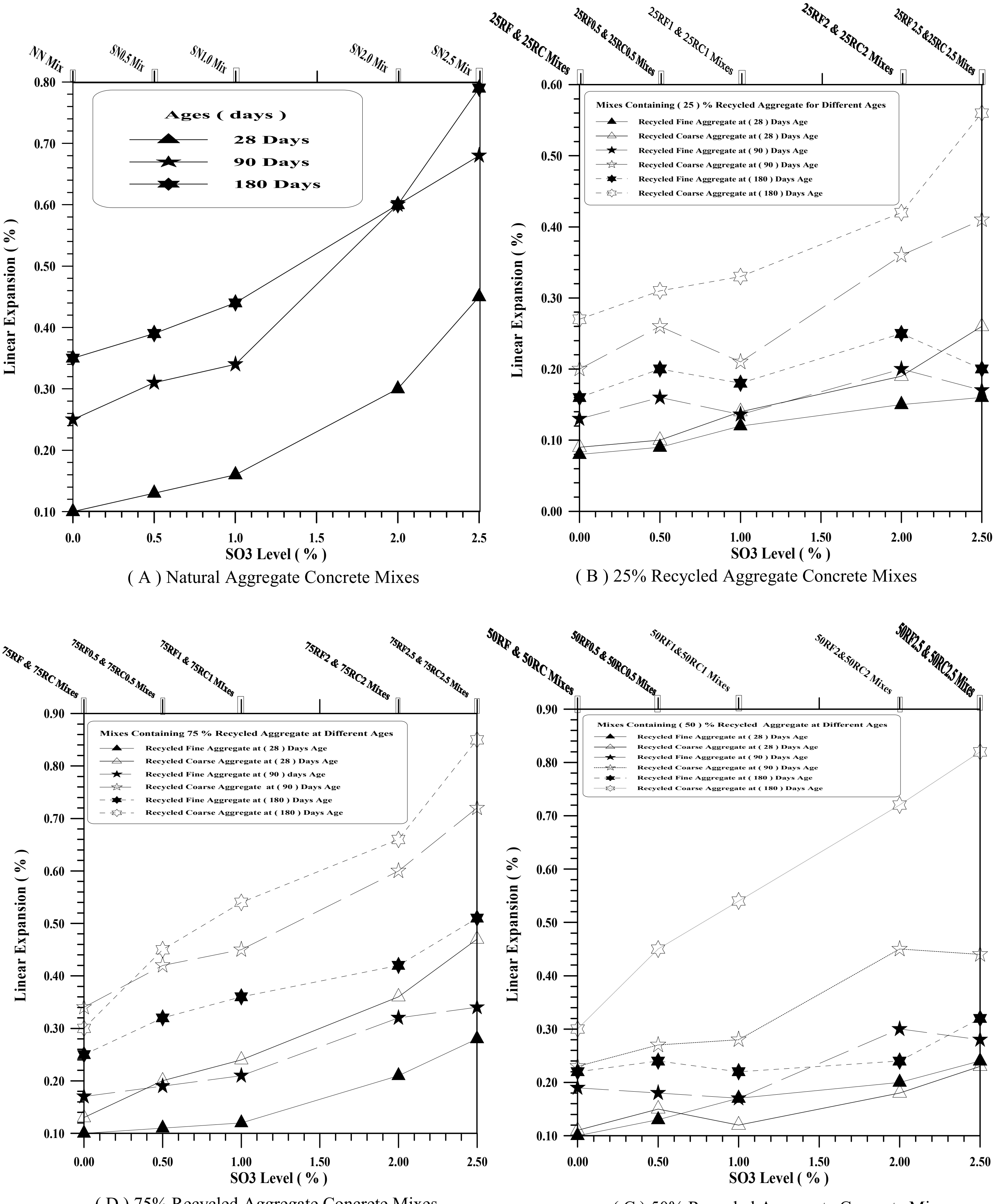
Conclusions and Recommendations :

Based on the recorded results of the properties studied , the mentioned mixes exclusive, the conditions of the work done here, and on the basis of an acceptable to a practical reduction occurrence in the strength of about 10%, the following conclusions and recommendations can be drawn :

1. RAC can be produced successfully without any detrimental ,or with limited variations in the strength and expansion. Recycled coarse aggregate concrete was more susceptible than recycled fine aggregate concrete to recycled process .
2. Partial replacement levels process up to the (75%) of recycled coarse aggregate or fine aggregate is practically possible for SO_3 levels of (0.5% to1.0%) and (0.5% to 2.0%) respectively , at all the investigated ages.
3. Full replacement levels process by one type recycled aggregate is practically possible at all the investigated ages for SO_3 levels (0.5% to 1.0%) . In the case of full replacement levels for both natural aggregates , SO_3 level must be not exceed (0.5%) .
4. Fifty percent replacement levels process by both recycled fine and coarse aggregates is practically possible for SO_3 levels up to (1.0%) at all ages investigated .
5. Not all expansions were destructive upon the physical structure of the (RAC) and strength thereafter, some of these expansions were reflected positively at the early ages when the concrete is not matured.

Table (10) : Results of the Tests for Linear Expansion and Compressive Strength Properties

Mixture Code	Linear Expansion * 10 -4			Compressive Strength Mpa			Mixture Code	Linear Expansion * 10 -4			Compressive Strength Mpa		
	28 Days	90 Days	180 Days	28 Days	90 Days	180 Days		28 Day s	90 Days	18 0Days	28 Days	90 Days	180 Days
NN	0.10	0.25	0.35	45	47	50	25RC2.0	0.18	0.35	0.42	38	40	37
SN0.5	0.13	0..30	0.38	47	48	52	25RC2.5	0.25	0.40	0.56	36	37	35
SN1.0	0.16	0.33	0.44	48	50	53	50RC	0.10	0.23	0.30	30	32	35
SN2.0	0.30	0.60	0.60	41	42	35	50RC0.5	0.15	0.26	0.45	33	36	38
SN2.5	0.46	0.68	0.80	35	32	30	50RC1.0	0.12	0.27	0.54	37	38	36
25RF	0.08	0.13	0.16	34	36	40	50RC2.0	0.16	0.44	0.72	28	27	26
25RF0.5	0.10	0.16	0.20	37	39	42	50RC2.5	0.21	0.42	0.82	25	22	20
25RF1.0	0.12	0.13	0.17	40	41	43	75RC	0.13	0.34	0.30	30	32	33
25RF2.0	0.14	0.18	0.24	41	43	39	75RC0.5	0.20	0.42	0.36	37	38	39
25RF2.5	0.15	0.16	0.18	39	40	37	75RC1.0	0.23	0.46	0.54	35	36	38
50RF	0.10	0.19	0.22	34	36	42	75RC2.0	0.35	0.60	0.66	30	27	25
50RF0.5	0.13	0.17	0.24	41	43	45	75RC2.5	0.45	0.72	0.85	23	22	18
50RF1.0	0.16	0.16	0.21	45	46	48	100RC	0.10	0.45	0.75	25	26	29
50RF2.0	0.20	0.28	0.24	43	40	42	100RC0.5	0.25	0.60	0.95	30	31	33
50RF2.5	0.22	0.26	0..30	39	35	36	100RC1.0	0.30	0.70	1.1	31	29	32
75RF	0.10	0.17	0.25	40	42	43	100RC2.0	0.50	1.30	1.55	21	25	28
75RF0.5	0.11	0.19	0.32	45	46	45	100RC2.5	0.70	1.50	2.40	17	22	25
75RF1.0	0.12	0.20	0.35	48	50	47	50RFC	0.10	0.20	0.25	20	22	23
75RF2.0	0.20	0.30	0.40	44	42	35	50RFC0.5	0.15	0.25	0.30	22	24	25
75RF2.5	0.27	0.32	0.50	41	36	33	50RFC1.0	0.17	0.20	0.40	19	21	20
100RF	0.10	0.25	0.80	28	31	33	50RFC2.0	0.19	0.35	0.60	15	19	18
100RF0.5	0.15	0.45	0.95	32	35	39	50RFC2.5	0.20	0.40	0.90	14	18	16
100RF1.0	0.20	0.55	1.1	34	36	38	100RFC	0.30	0.50	0.55	18	19	21
100RF2.0	0.40	1.1	1.5	23	33	35	100RFC0.5	0.40	0.60	0.65	20	21	22
100RF2.5	0.85	1.4	2.0	21	28	30	100RFC1.0	0.45	0.65	0.75	17	18	16
25RC	0.09	0.20	0.27	33	35	38	100RFC2.0	0.65	1..1	1.3	14	17	12
25RC0.5	0.10	0.26	0.32	35	38	40	100RFC2.5	1.05	1.5	2.1	12	15	10
25RC1.0	0.14	0.20	0.34	37	39	42							



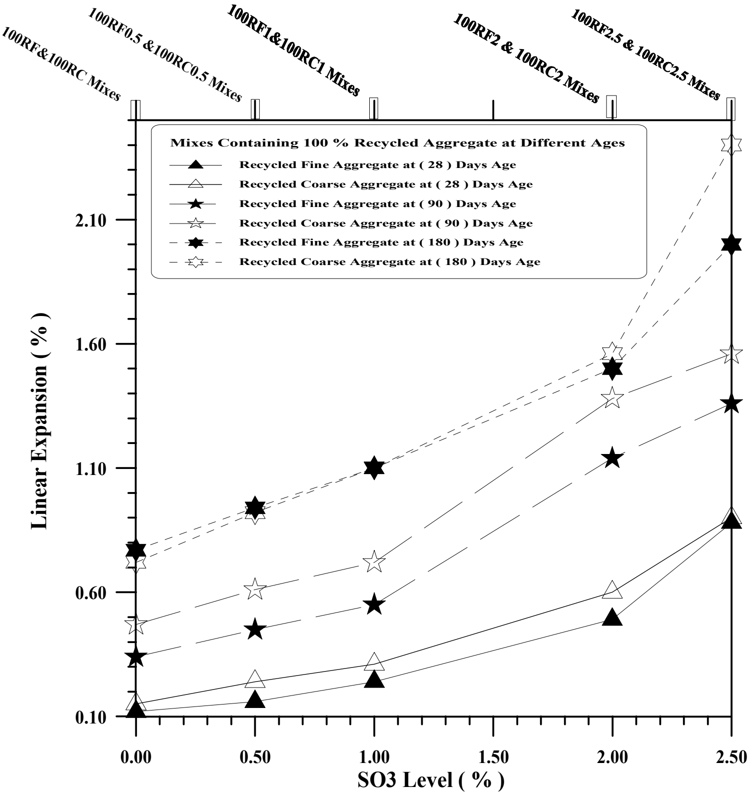
(A) Natural Aggregate Concrete Mixes

(B) 25% Recycled Aggregate Concrete Mixes

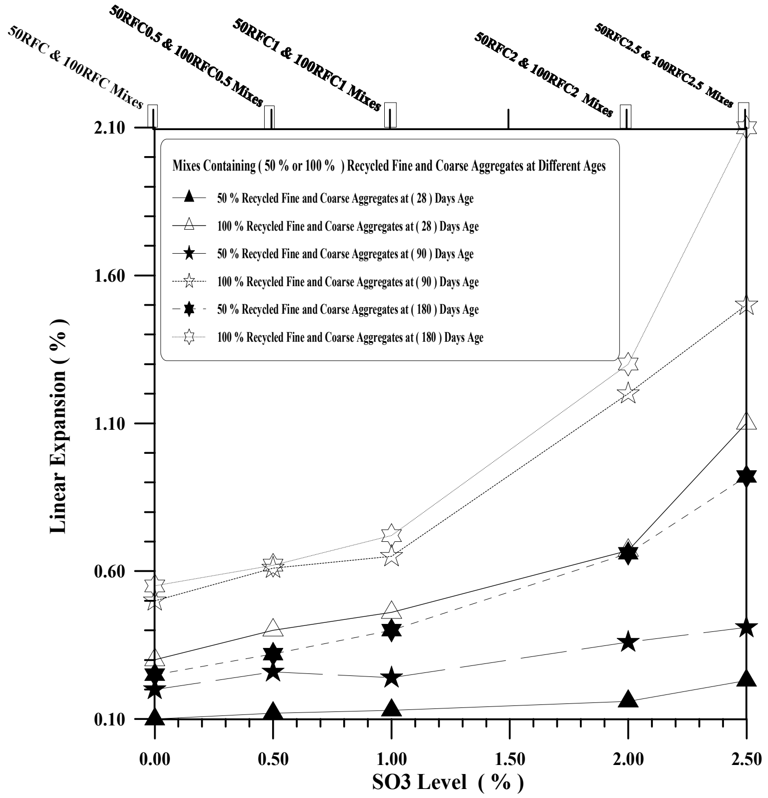
(D) 75% Recycled Aggregate Concrete Mixes

(C) 50% Recycled Aggregate Concrete Mixes

Fig. (4_ 1) : Relation between Linear Expansion versus SO_3 Levels at the Different Ages Indicating the Types of the Tested Concrete Mixes on the Unified X axis

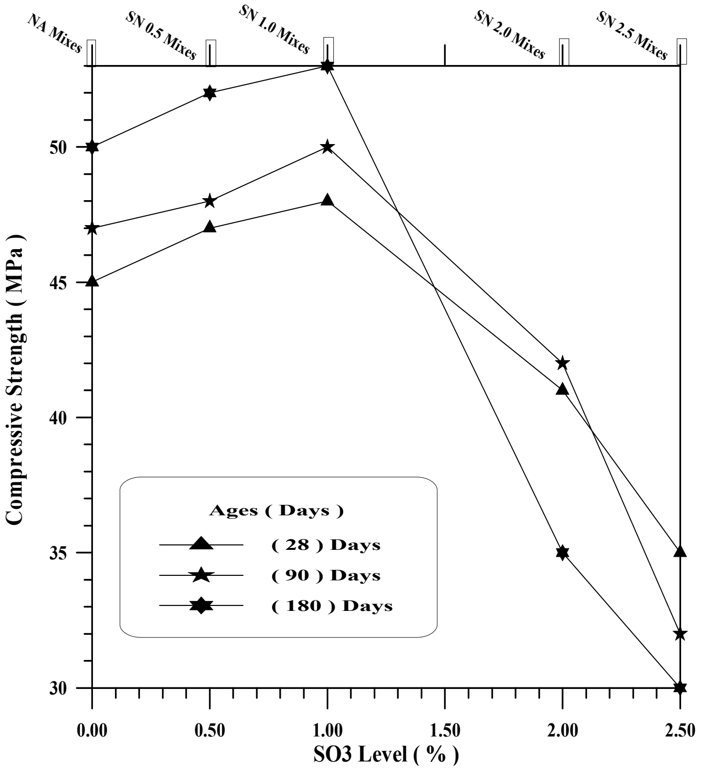


(E) 100% Recycled Aggregate Concrete Mixes

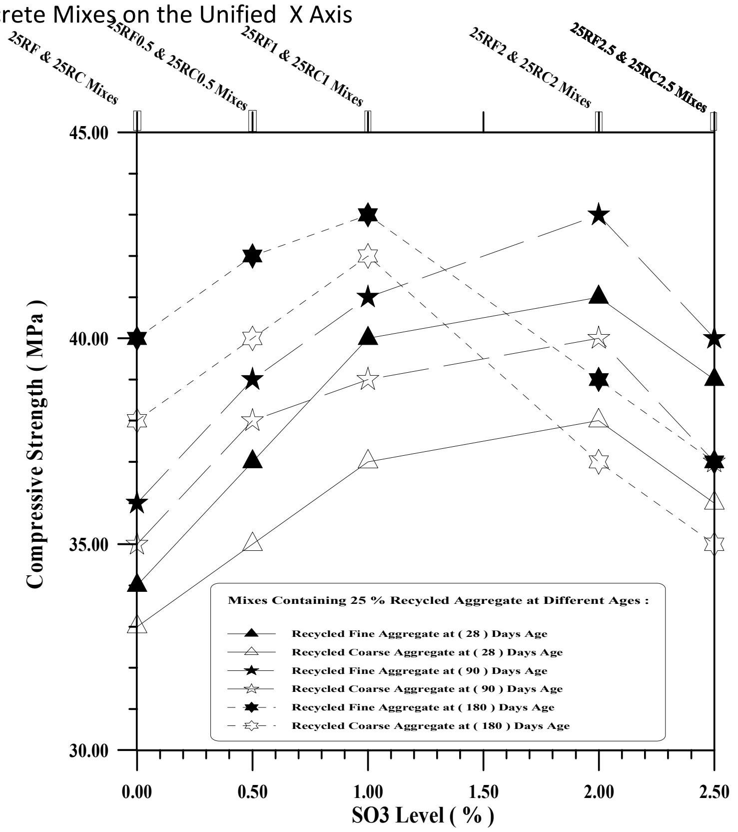


(F) 50% or 100% Recycled Fine and Coarse

Continue to the Fig. (4 _ 1) : Relation between Linear Expansion versus SO_3 Levels at the Different Ages Indicating the Types of the Tested Concrete Mixes on the Unified X Axis



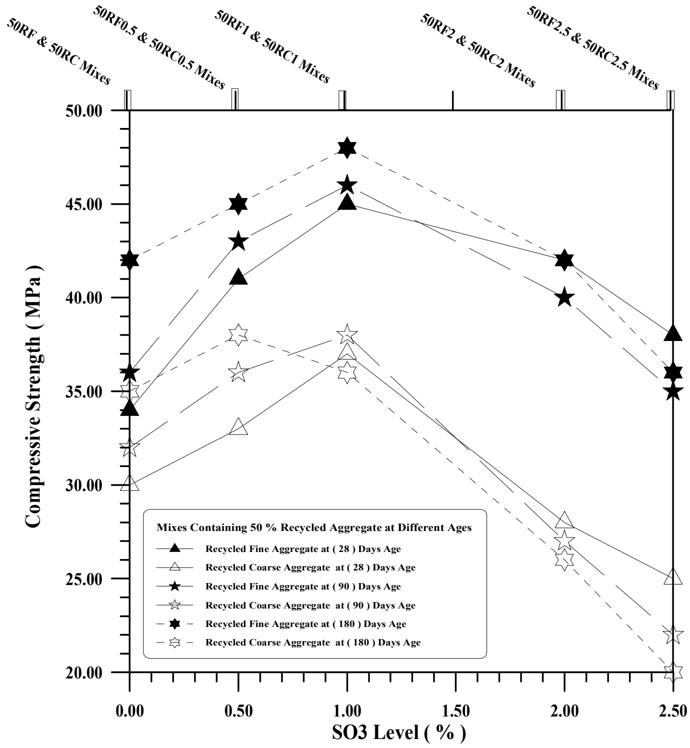
(A) Natural Aggregate Concrete Mixes



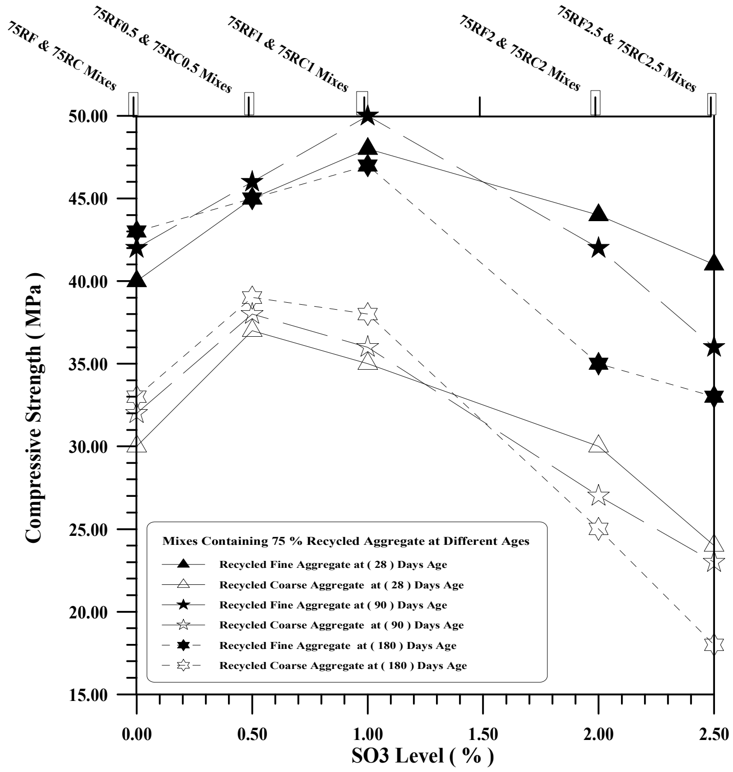
(B) 25% Recycled Aggregate Concrete Mixes

Fig. (4 _ 2) : Relation between Compressive Strength versus SO_3 Levels at the Different Ages Indicating the Types of the Tested Concrete Mixes on the Unified X Axis

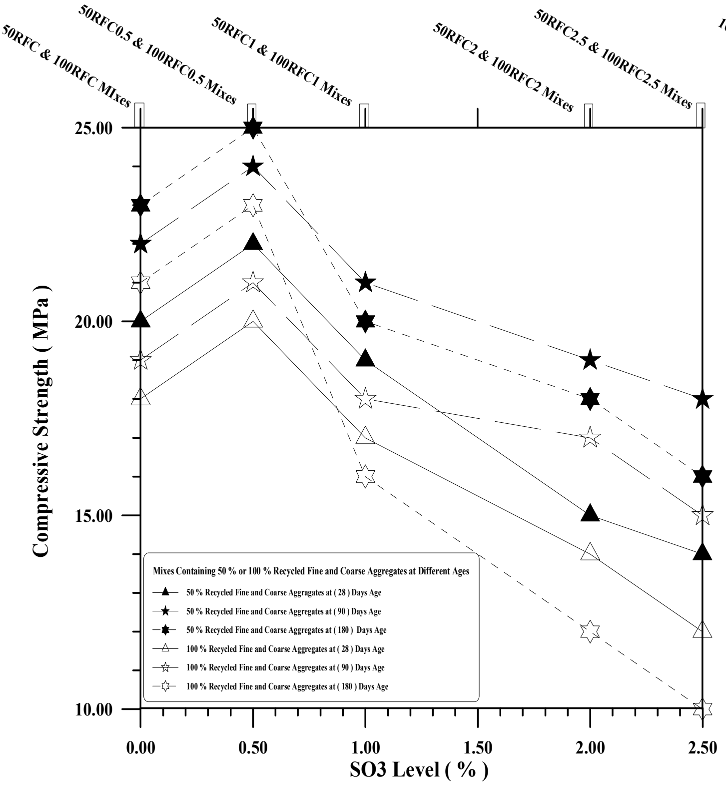
Fig. (4 _ 2) : Relation between Compressive Strength versus SO_3 Levels at the Different Ages Indicating the Types of the Tested Concrete Mixes on the Unified X Axis



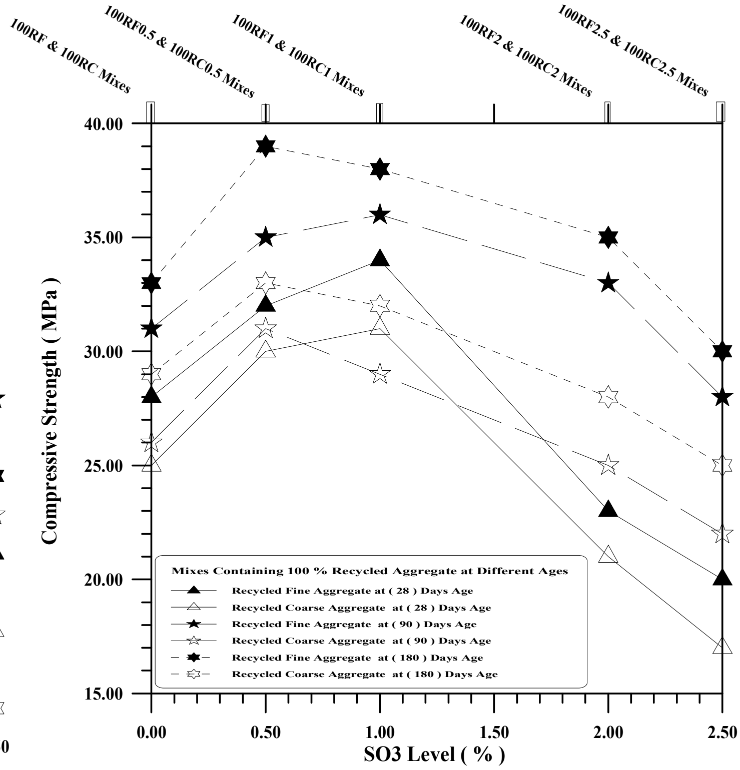
(C) 50% Recycled Aggregate Concrete Mixes



(D) 75% Recycled Aggregate Concrete Mixes



(F) 50% or 100% Recycled Fine and Coarse Aggregates Concrete Mixes



(E)

100% Recycled Aggregate Concrete Mixes

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