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Extension and Strength Properties Of Cement Containing Reused Solid Total

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A B S T R A C T: *In the Middle East locale, inside dividers of structures are generally put with gypsum. Hence, the destruction squanders are presumably gypsum sullied, which may prompt inward sulfate assault in new cements containing reused concrete. This examination gives the findings of a test examination on cement made with reused solid totals defiled with development gypsum (unhydrous calcium sulfate). For this, four gatherings of blends were readied. In the first gathering, the characteristic sand was part of the way and completely supplanted by tainted fine reused solid total. In the subsequent gathering, the regular rock was incompletely and completely subbed by debased coarse reused solid total. In the third gathering, both sand and rock were subbed by polluted reused solid total, while the fourth gathering was coordinated to examine the impact of silica rage on cement made with reused solid total. The deliberate properties were development, compressive strength, parting rigidity and modulus of burst. The outcomes demonstrated that the higher the rate level of tainted reused totals the lower the strength and the higher the extension. The best outcomes were recorded for the second gathering of blends. In all cases, the development didn't surpass the restriction of 0.05%.*

Keywords: *Contaminated ;aggregate; Recycled aggregate ;Expansion; Strength; Gypsum ;Silica fume*

I. INTRODUCTION

Theoutputofhugeamountsofsolidwastesisoneofthemostunfavorableconsequencesoftheglobal populatio andeconomygrowth.ConstructionandDemolitionWastes(CDW)areoneofthemost commonandlargestmu nicipalwastesthatimposeenormouscostsoflandfillmanagementandtransportationbesidestheirnegativeim pactontheenvironment.In Europe for example, 34% of more than 2500 million tons of annual solid wastes is CDW [1]. On the other hand, the huge constructionworkslead toconsumehugequantitiesofnaturalfineandcoarseaggregates.Thedemandofnaturalaggregate for construction industry has been doubled during the last 10 years reaching an annual of 40 billion tons [2]. A remedy solution to these problems is the recovery and the recycling of old concretes to produce concrete aggregates. The annual global CDW output exceeds 2000 million tons with an average recovery percentage of more than 50% [2]. The recovery percentage ranges from less than 10% in some developing countries to more than 90% in countries like Taiwan, Japan, Denmark and Netherlands[2,3].

ThepropertiesofnewconcretemadewithRecycledConcreteAggregate(RCA)mayvarydependingon(1)thes trengthofoldconcretefromwhichtheRCAisderived,(2)theprocedureofproducingRCA,and(3)themoisture conditionoftheRCA. Accordingly, there is a contradiction between the authors regarding some properties of concrete produced withRCA.Thevastoftheliteraturereviewshowedthatusing50%RCAormorewouldadversely affectthemec hanicalpropertiesofconcrete.However,somestudiesshowedthattheuseofRCAinconcreteisnotalwaysunfa vorableandgoodpropertiesmay be achieved when the mix proportions are selected carefully [4–8]. Indeed, the material characteristics like strength, modulusofelasticity,dryingshrinkage,waterabsorption,totalporevolumeandcarbonationarenotsignifi cant lyalteredwhenabout20%ofvirginaggregateisreplacedbyRCA[915].Otherpreviousresearchersshowedtha tcompressivestrength may be comparable or slightly greater when recycled aggregate from better qualityconcretesourcesisused[1620].However,theuseoffineRAmayincreasethetimedependentstrainsincl udingcreepanddryingshrinkagebecausethistypeofrecycledaggregatecontainsoldmortarsandcementpaste s[10].

Somereinforcedconcretememberssuchaswallsandslabsarefinishedwithconstructiongypsumand plasterofParis.Therefore,thedemolitionwastesderivedfromthesemembersarecontaminatedwithgypsum. Thepresenceofgypsummayleadtocompositioninducedinternalsulfateattack.Thistypeofat tackisgenerated atnormaltemperaturesduetotworeactions.ThefirstreactiontakesplaceandoccursbetweengypsumandC_3A withthepresenceofwaterproducingettringite,whilethesecondhappensbetweencalciumsulfatefromgypsu mandthemonosulfatephasethatpresentinthehydratedcementpasteproducingexpansiveettringite.Theformerreactioninitiatesdirectlyaftermixinganditisnecessarytocontrolsetting, it becomes unfavorable when it generates beyond setting stages because of the formation ofexpansiveettringite.Some previous researches were found in the literature about the effect of internal attack of sulfate onthemechanicalpropertiesanddurabilityofconcretesandmortars[9,21–23].AstudycarriedoutontheexpansionofmortarsincorporatedwithfineRCAshowedthattheexpansionofmortarsdidnotexceedtheexpansionlimitof0.1%availableintheliteraturethoughtheSO_3contentinthesandwas2.9%[9].Thisencouragingfindingwasvalidirrespectiveofthetypeofcementused.Otherstudies[22,23]usedfineaggregatewithdifferentgypsumcontaminationcontentsasareplacementofsilicasandinultra-highperformanceconcrete.Theyshowedthatlowgypsumcontentscouldslightlyincreasethecompressiveandsplittingstrengthsofconcretesamples,whilesuchresultswasnotobservedforordinarymortars.Theyalsoshowedthatthe expansion of contaminated mortars was noticeably higher as the gypsum content increased.

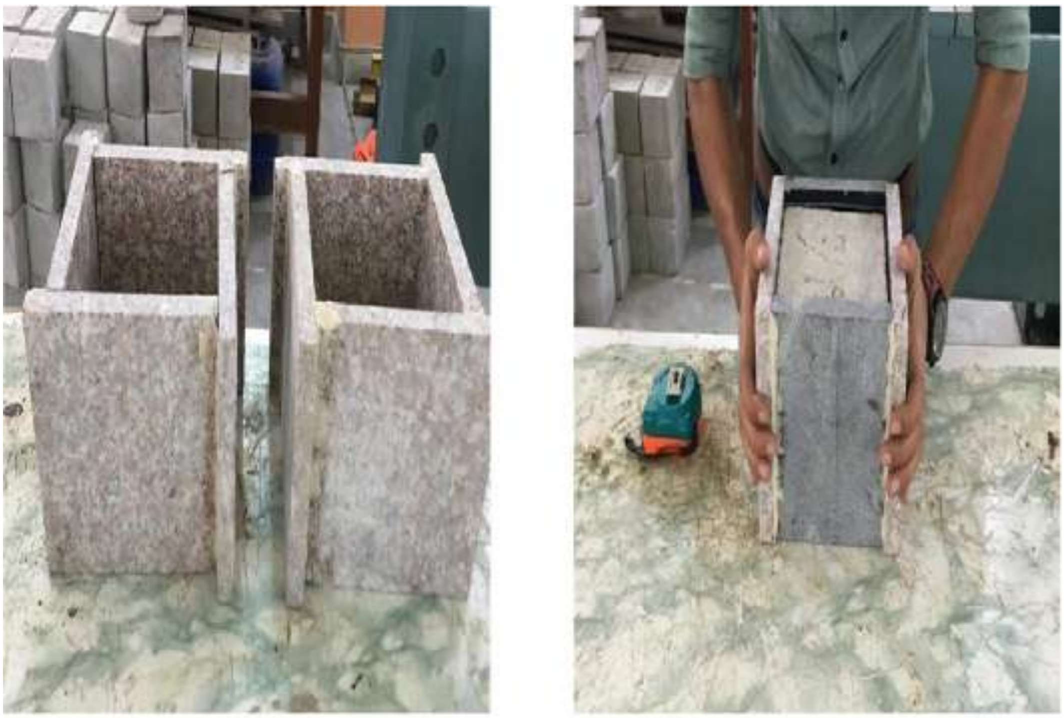
II. RESEARCH SIGNIfiCANCE

Asintroduced,manystudieswerecarriedoutoneitherRCAorgypsumcontaminatedaggregate.However,verylimitedinformationisavailableregardingthebehaviorofconcretewhenRCAiscontaminatedwithgypsum. Theselimitedstudies were focused on mortars rather than concretes. Besides, the effects of RCA contaminated with gypsum on the strength properties were not previously studied. Therefore, further information is still required dealing with the strength and durabilityofthistypeofconcrete.Thepresentstudyhasinvestigatedthestrengthanddurabilitycharacteristics ofconcrete made with gypsum contaminated fine and coarse RCA with different replacement dosages ranging from 0 to 100%. The sourceofthecontaminatedrecycledaggregatewascrushedgypsum-plasteredconcretecubes.Theinvestigatedproperties wereexpansion,compressivestrength,splittingtensilestrength,andmodulusofrupture.

III. EXPERIMENTALWORK

1.1. Materials

TheordinaryPortlandcement(ASTMtypeI)havingafinenessof312m^2/kgandspecificgravityof3.15g/cm^3wasusedinthisstudy,whilesilicafumewithafinenessof21,100m^2/kgandspecificgravityof2.2g/cm^3wasalsoutilizedinsomemixes.LocalgradednaturalfineandcoarseaggregatesfromWasitprovince/Iraqwereadoptedintheexperimentalwork.GypsumcontaminatedRCAswerealsousedasfineandcoarseaggregates.Inordertosatisfytherequiredworkability,highrange water reducer admixture was added to somemixes.



(a) plastering molds (b) preparing cubes for plastering

Fig. 1. Gypsum-plastering of cubes made as source contaminated recycled concrete.

1.2. Preparing gypsum contaminatedRCA

TheproducingmethodofgypsumcontaminatedRCAwasasfollows:(1)asufficientnumberofconcretecubes werecastfromnaturalaggregatetoproduceaconcretewithacubecompressivestrengthof25MPa.(2)Thecube swerecuredupto28days,thentheywereplasteredwithgypsum(unhydrouscalciumsulfate)fromaonesidewit hathicknessof12mm.Fig.1showstheprocessofpreparationandplasteringofthesourceconcretecubes.(3)Aft erthat,thecubeswerecrushedtoobtainthegypsumcontaminatedRCA.Toassurethatalltheplasteringgypsum isincludedintherecycledaggregate,thecubeswerefirstkeptinplasticbagsandcrushedinacompressionmachi nebeforecrushingtofinerparticles.Fig.2showsapatchof sourcegypsum-plasteredcubes,whileFig.3showstheinitialcrushingprocessofthesecubes.ThegradationofRCAswas adjusted manually so that it became similar tothat of natural aggregates. The sieve analysis of the recycledaggregatesispresentedinFig.4.Thecontentofacidsolublesulfates,SO_3inthegypsumcontaminated RCAwas1.5%byweight.InordertocompensateforthehighwaterabsorptionofRCAs,theywerepresoakedin waterfor24hpriortocasting.

1.3. Preparing, mixing andtesting

Thereferencemixhasbeendesignedwithatargetcompressivestrengthof25MPa.Theconcretemixesareclass ifiedintofourgroups.AsshowninTable1,threetypesofaggregatereplacementmethodswereadopted,namely sandreplacement,gravelreplacementaswellasbothsandandgravelreplacement.Thereplacementlevelswer e20,40,60,80,and100%.Inotherwords,thenaturalsandwaspartiallyandfullyreplacedbyfineRCAinaGroup Amixes.InGroupBmixes,thegravelwassubstitutedbycoarseRCAatvariouslevels.InGroupC,bothsandand gravelwerereplacedwithfineandcoarseRCAs.Inthefourthgroup(GroupD)andtomonitortheinfluenceofsili cafume,itwasincorporatedinthemixeswiththehighest replacementlevel.

The concretes were mixed in a drum type mixer of 0.1 m^3 capacity. Initially, aggregates with a small quantity of water were mixed. Thereafter, the cement and silica fume with the rest of water were added and mixing was resumed until a homogenous mixture wasachieved.

The testing methods of hardened concretes involved expansion, compressive strength, splitting tensile strength, and modulus of rupture for third point bending samples. The specimens used were 100 mm cubes for compressive strength,

× 150 300 mm cylinders for splitting tensile strength × × and 100 100 400 mm for both expansion and modulus ofrupture. The strength properties were measured after 7, 28, and 90 days of curing in water, while the expansion was measured at specified ages up to 6 months of curing in water. Immediately after demolding, two demec points were glued on each expansionsampletomeasurethelengthchangeviaextensometeratthespecifiedages.

IV. RESULTS AND DISCUSSION

1.4. Compressivestrength

Figs.57toshowtheeffectofreplacementlevelofsand,gravelandbothofthembyRCAonthecompressivestrengthofconcrete.Itcanbeseenthat,thecompressivestrengthdecreasedwithincreasingtheRCAreplacementlevelirrespectiveofthereplacementtype.However,thehighestdecrease,whichvariedfrom6to38%,wasrecordedformixesofGroupCinwhichboththesandandgravelwerereplacedbyrecycledaggregates.ThespecimensofgroupA,inwhichsandwasreplacedbyfineRCA,showedthesecondhighestdecreaseincompressivestrengthof7to31%.Ontheotherhand,thecompressivestrengthoftheGroupBmixeswaslessaffectedbythesubstitutionofcoarseaggregatebycoarseRCAsuchthatthehighest recorded percentage decrease was27%.

60

40

Fig. 2. A batch of source gypsum-plastered cubes.

Fig. 3. Initial crushing of source cubes.

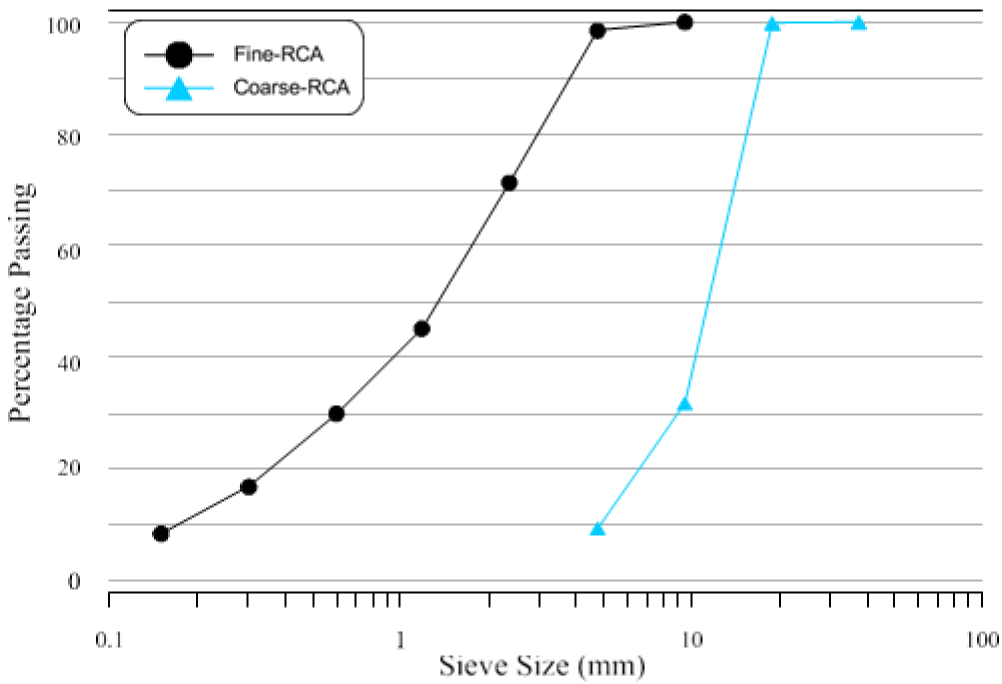


Fig. 4. Sieve analysis of fine and coarse RCA.

ThecompressivestrengthbehaviorofthenewconcretederivedfromRCAcouldberelatedtothelowqualityofsourceconcreteaswellastheporousinterfacialtransitionzonebetweenaggregateandcementpaste.Manypreviousstudiesalsoprovedtheadversenessofthestrengthofconcretemadefromrecycledconcreteaggregate[11,12,14,2426].Inthepresentstudythecombinationeffectofgypsumandrecycledconcreteaggregatealsoledtodecreasethecompressivestrengthofthe new concrete. Furthermore, the decrease in compressive strength was higher in sand replacement as comparedto gravel replacement. Gesoglu et al. [23] reported a continuous decrease with the increase of gypsum content in the compressive strengthofcementmortarsmadeofcontaminatedfineaggregates.Theyshowedthatthestrengthdecreasereacheduptoapproximately40%foragypsumcontentof11.5%.Thehigherspecificsurfaceareaofgypsumparticlesthatwerepresentin fine recycled aggregate compared to those present in coarse aggregate accelerates theinteractionbetweenfinegypsumparticlesandC_3Aandleadstoproducemoreettringite.Furtherstrengthdeteriorationoccurredwhenbothsandandgravel were substituted by contaminated RCA because of the accumulated higher gypsum content in theseaggregates.

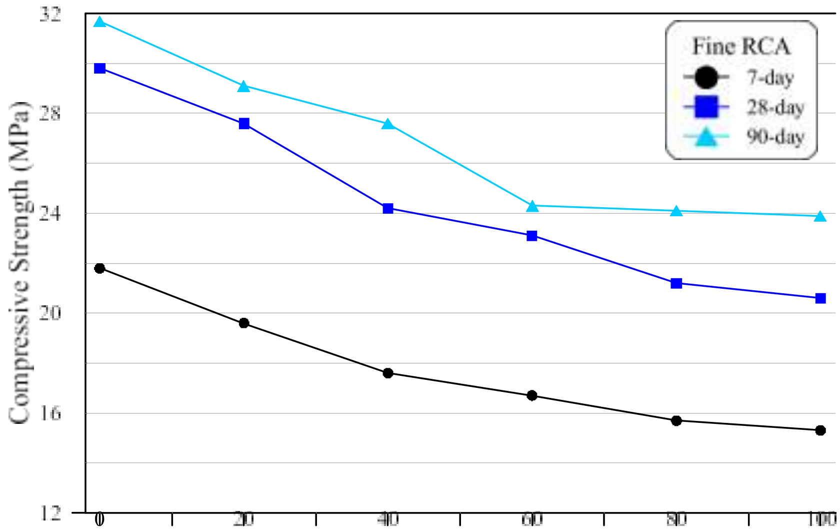
When the strength development of the mixes was considered, it can be seen that all the mixes even those with high gypsum content developed strength with age as shown in Figs. 5–7. The growth in strength could be related to the continuousinteractionofcementandcuring water.Moreover,someporeswereeventuallyfilledwithettringite.Ouyang et al. [27] found that the compressive strength increases with age initially and then dropped depending on the C_3A and cement content in the mix. The apparent contradiction between both studies could be related to the much higher SO_3 contentusedinthepreviousone(7%)ascomparedtothecurrentone(2%).

Table 1

Mix proportion of concrete (kg/m^3).

Specimen'sGroup	CodeNumber	Cement	Silicafume	Water	SP	Coarseaggregate		Fineaggregate		w/b	Slump(mm)
						NCA	RCA	NFA	RFA		
Reference	CM	380	0	210	0	980	0	790	0	0.5 5	95
A	MRC20	380	0	210	0	784	196	790	0	0.5 5	90
	MRC40	380	0	210	1.9	588	392	790	0		95

										0.55	
	MRC60	380	0	210	1.9	392	588	790	0	0.55	90
	MRC80	380	0	210	2.28	196	784	790	0	0.55	85
	MRC100	380	0	210	2.28	0	980	790	0	0.55	85
B	MRF20	380	0	210	0	980	0	632	158	0.55	90
	MRF40	380	0	210	0	980	0	474	316	0.55	85
	MRF60	380	0	210	2.28	980	0	316	474	0.55	80
	MRF80	380	0	210	2.66	980	0	158	632	0.55	85
	MRF100	380	0	210	3.42	980	0	0	790	0.55	85
C	MRCF20	380	0	210	1.9	882	98	711	79	0.55	85
	MRCF40	380	0	210	2.28	784	196	632	158	0.55	80
	MRCF60	380	0	210	3.04	686	294	553	237	0.55	80
	MRCF80	380	0	210	3.42	588	392	474	316	0.55	75
	MRCF100	380	0	210	2.8	490	490	395	395	0.55	70
D	MRC100S	342	38	210	1	0	980	790	0	0.55	80
	MRF100S	342	38	210	1	980	0	0	790	0.55	80
	MRCF100S	342	38	210	1.1	490	490	395	395	0.55	75



Replacement Level (%)

Fig. **5.** Variation of compressive strength with contaminated fine RCA.

15. Splitting tensile strength and flexuralstrength

Concrete is known for its weakness in tension. One of the tests used to evaluate the tensile strength of concreteisthesplittingtest.Thesplittingtensilestrengthofconcreteissensitivetotheaggregatetypeandisrelatedtothecompressive strength. On the other hand, the flexural beam test (modulus of rupture) can be usedasanindicatorforboththeflexuralstrengthandindirectlythetensilestrength.Therefore,boththesplittingtensileandtheflexuraltestswereconductedinthis researchtoevaluatetheeffectoftheincorporationofsulfate-contaminatedRCA.ThetestresultsofthesplittingtensilestrengthfortheconcretemadewithcontaminatedRCAarepresentedinFigs.8,10.Aswiththecompressivestrength,thesplittingtensilewasadverselyaffectedbytheinclusionofRCAandthehigherthe substitution level the lower the retained strength. In all cases, the reduction in strength was increased as thesubstitution level increased. Fig. 8 shows that for fine RCA replacement and for the three ages of concrete, the reductions in splitting tensilestrengthwereintherangesofapproximately9–13%,17–20%,21–28%,28–35%and31–35%forreplacementlevelsof 20,40,60,80and100%,respectively.Ontheotherhand,lowerreductionlevelswererecordedforcoarseRCAreplacementsasshowninFig.9.ForcoarseRCAreplacementlevelsof40,60,80and100%andforthethreetestages,thepercentage

0 20 40 60 80 100

Replacement Level (%)

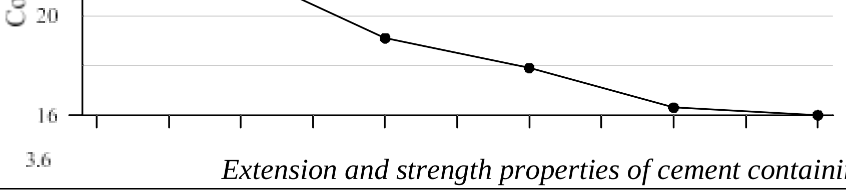


Fig. 6. Variation of compressive strength with contaminated coarse RCA.

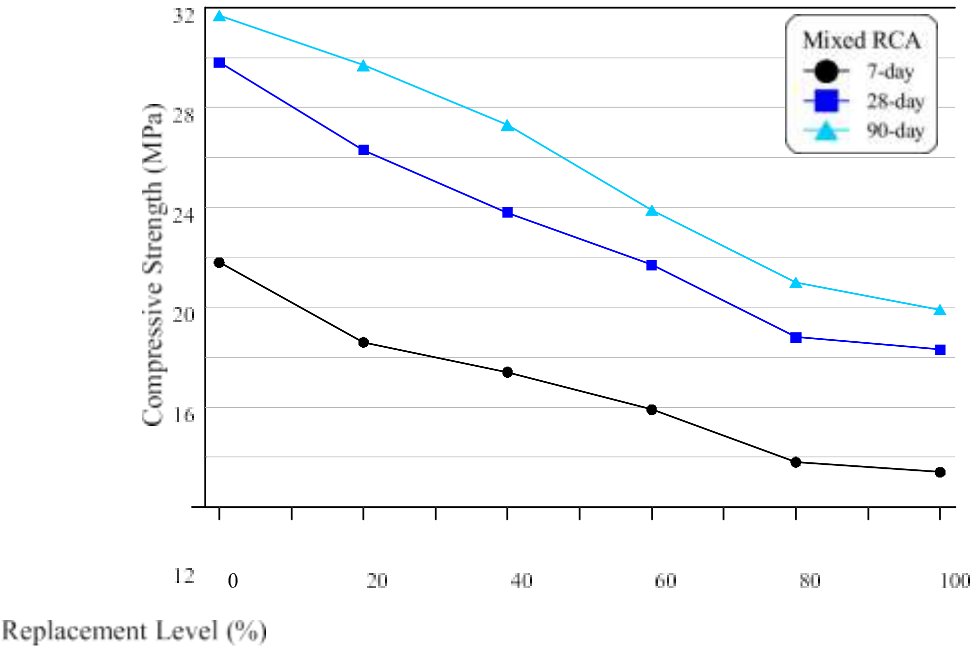


Fig. 7. Variation of compressive strength with contaminated mixed RCA.

reductionsinsplittingtensilestrengthwereapproximatelyintherangesof8–17%,16–21%,20–31%and22–33%,respectively, while strength gain was recorded for some samples at a replacement level of 20%. Thebetterresultsofthespecimensinwhichthegravelwaspartiallyandtotallyreplacedbycontaminatedcoarse RCAareattributedtotheslowdissolutionofcoarsegypsumparticlesinwater,whichisnotenoughtopromoteettringiteformation.Fig.10showsthedeclinedsplittingstrengthofspecimenswithmixedsubstitutionoffineand coarseRCA(GroupC).Thiscaseofreplacementledtothehighestlevelsofstrengthreductionamongthethreegroupsofspecimens.Forthethreetest ages, the strength reduction values were 7–39% when both natural aggregates were replaced by fine and coarse RCA comparedto935%foronlyfineRCAreplacementand6–33%forcoarseRCAreplacement.

Figs.11,13showthattheflexuralstrength(modulusofrupture)showedsimilartrendofdeclinewiththeincrease ofRCA replacement level. Similar to the splitting tensile strength, the fine RCA replacement was foundoflargerimpactontheflexuralstrengththanofcoarseRCAreplacement,whilethelargestreductionlevelsinflexuralstrengthwererecordedforthecaseofmixedRCAreplacement.Forthethreecuringages,therangesofpercentagereductionintheflexuralstrengthwere6–

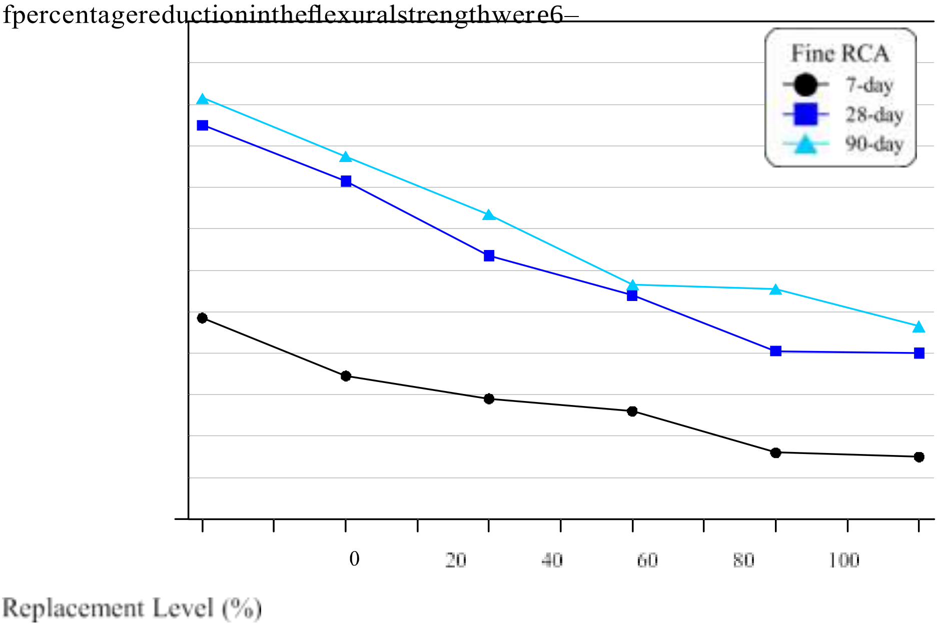


Fig. 8. Variation of splitting tensile strength with contaminated fine RCA.

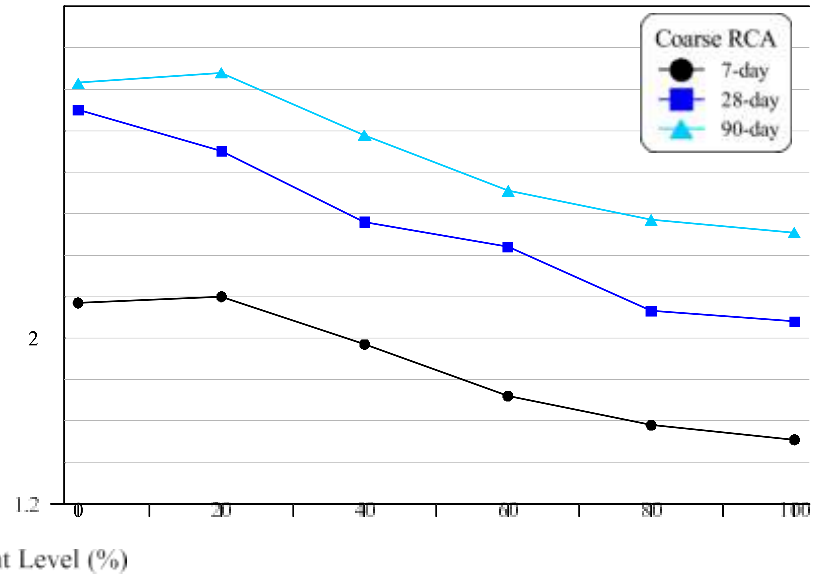


Fig. 9. Variation of splitting tensile strength with contaminated coarse RCA.

33%,028%and6,41%forfine,coarseandmixedRCAreplacements,respectively.Thisagaincanbeattributedt othefaster dissolution of the fine gypsum particles, which maximizes their negative impact by the formation of the undesirable ettringiteformation.

It is worth noting that the RCA which is resulting from old concrete contains both original parti cles as wellasmortaradheredonthem.ThenewmortarincorporatedwithRCA,therefore,consistsoftwointer facialtr ansitionzones;oneofthemispositionedbetweentheoriginalparticlesandtheadheredmortarwhiletheother on eislocatedbetweenthenewmortarandRCA.Thisgeneratestheweaknessregionsinthemicrostructureofthene wconcretesparticularlyunderthebending loads, and thus reducing the flexural strength and fracture energy of concrete. Some recent researches have investigated theseinterfacialtransitionzonesusingadvancedtechniques[28–31].

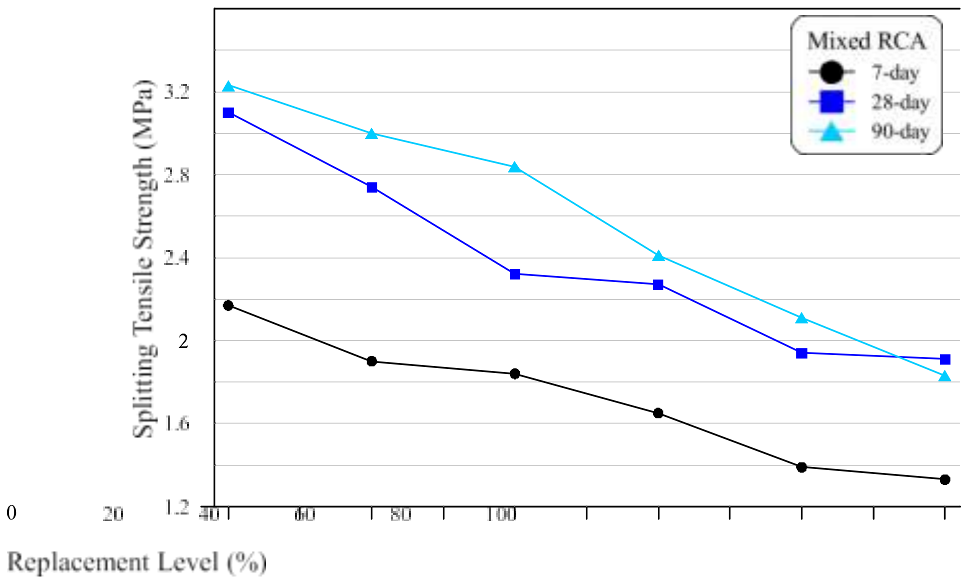


Fig. 10. Variation of splitting tensile strength with contaminated mixed RCA.

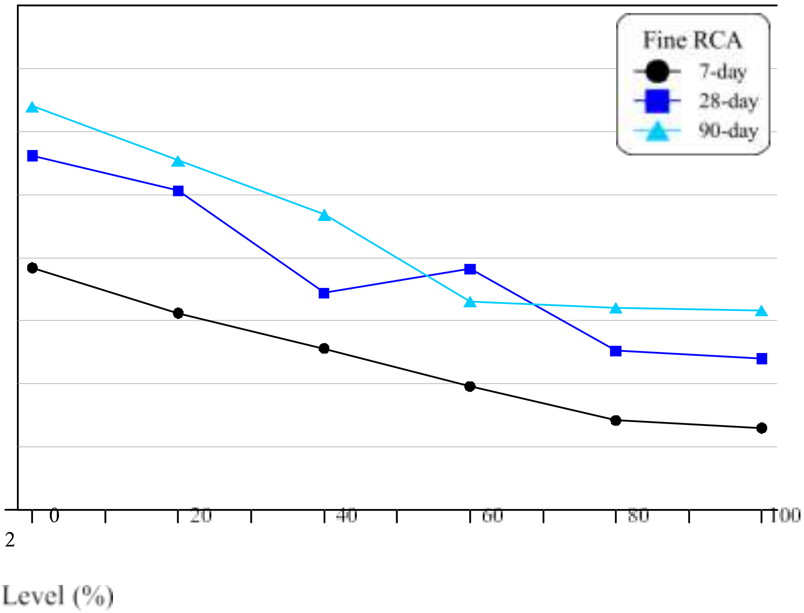


Fig. 11. Variation of modulus of rupture with contaminated fine RCA.

1.6. Expansion

Figs.14,16showthevariationofexpansionofconcretemadewithRCAwithage.Obviously,theexpansionofconcreteincreasedwithtime.Thisisbecausewhilemaintainingtheconcretesamplesin water,theCSHgelabsorbswaterandthemoleculesofwatercausetheparticlesofgeltofurtherapart.Withcuringtime,furthersmallswellingoccursasaresultofdecliningthesurfacetensionoftheCSHgel[32].Ineachgroupofmixes,theexpansionstrainwashigherwithincreasingthereplacementlevelofvirginaggregatebycontaminatedRCA.However,thehigheststrainswereobservedforGroupCmixes,wheremixedRCAwasused,becauseoftheirhighestSO_3contentinaggregatefollowedbythegroupoffineRCA (Group A), while the specimens of the Group B where coarse RCA was used showed the lowest strains. The maximum recordedexpansionsforthethreegroupswithreplacementsoffineRCA,coarseRCAandmixedRCAwere0.046,0.026,and

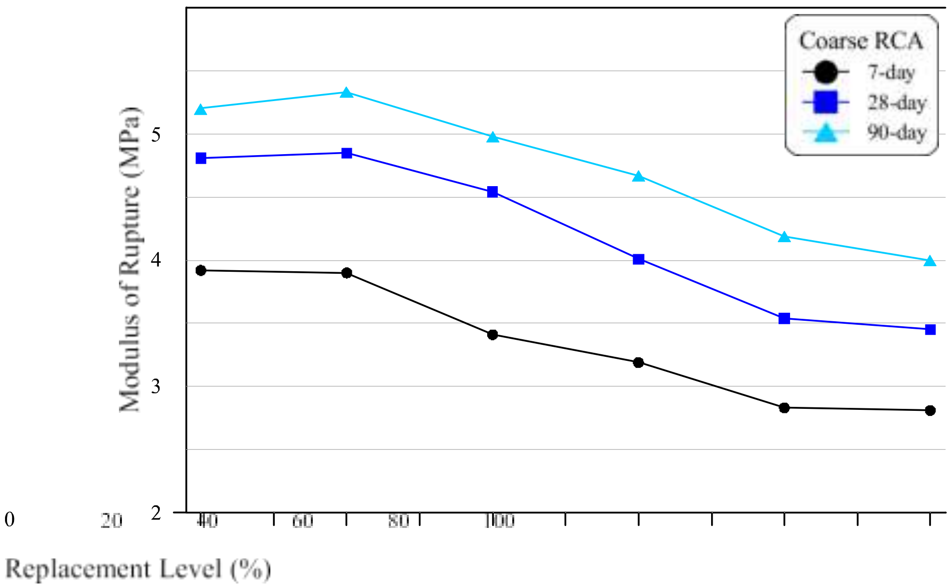


Fig.12. VariationofmodulusofrupturewithcontaminatedcoarseRCA.

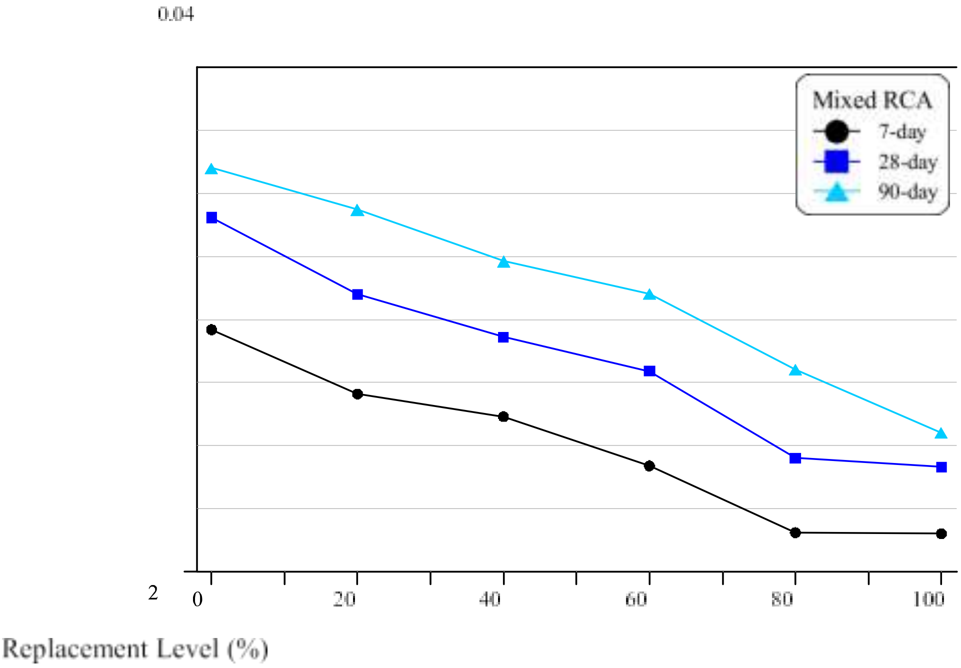


Fig. 13. Variation ofmodulus of rupture with contaminated mixed RCA.

0.048%, respectively. Thus, the results of expansion test fully support the results trend of the compressive and tensile strengths discussed earlier.

Indeed, increasing gypsum content in the mix leads to form further ettringite. The ettringite generated atearlyages(beforesetting)isnotharmfulandevennecessarytocontrolsetting.However,itbecome sadversen esswhenitdevelopslater(athardenedstage)becauseexpansionofhardenedmatrixdevelopscracksandhence weakensthesystem[32].Asreported by [33], the use of recycled concrete aggregates instead of natural aggregateincreasestheexpansionofconcrete,sotherelativelyhigherexpansivestrainsofmixeswithcontami natedaggregatesascomparedtocontrolmixeswerenotonlydue to the existence of excessive sulfates in aggregate but also due to recycled concrete aggregates. However, it is difficult to distinguishtheeffectoftheadheredmortarontherecycledaggregateparticlesfromtheeffectofthegypsumbec auseeach oneofthemmayincreasetheexpansionstrain.

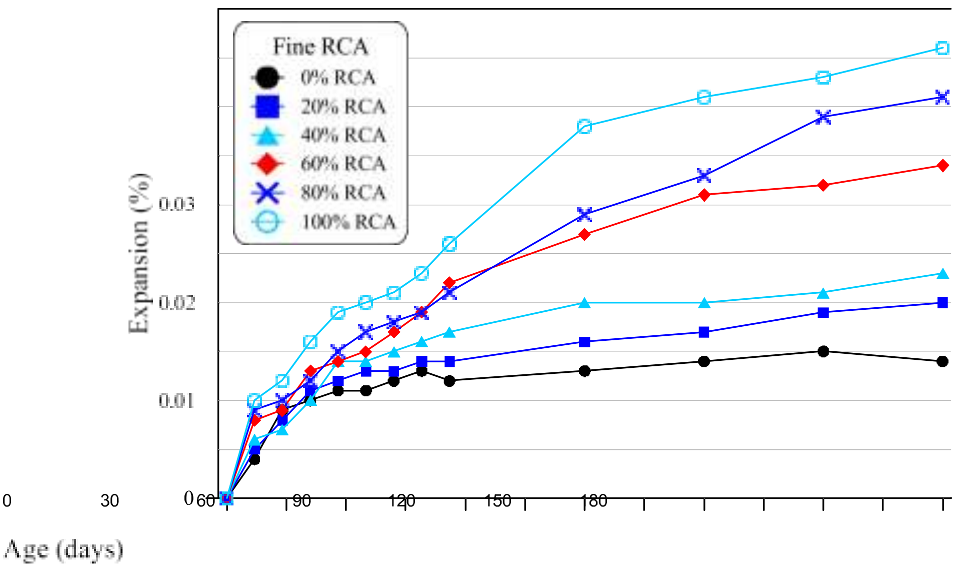


Fig. 14. Expansion with time for concrete with different contaminated fine RCA contents.

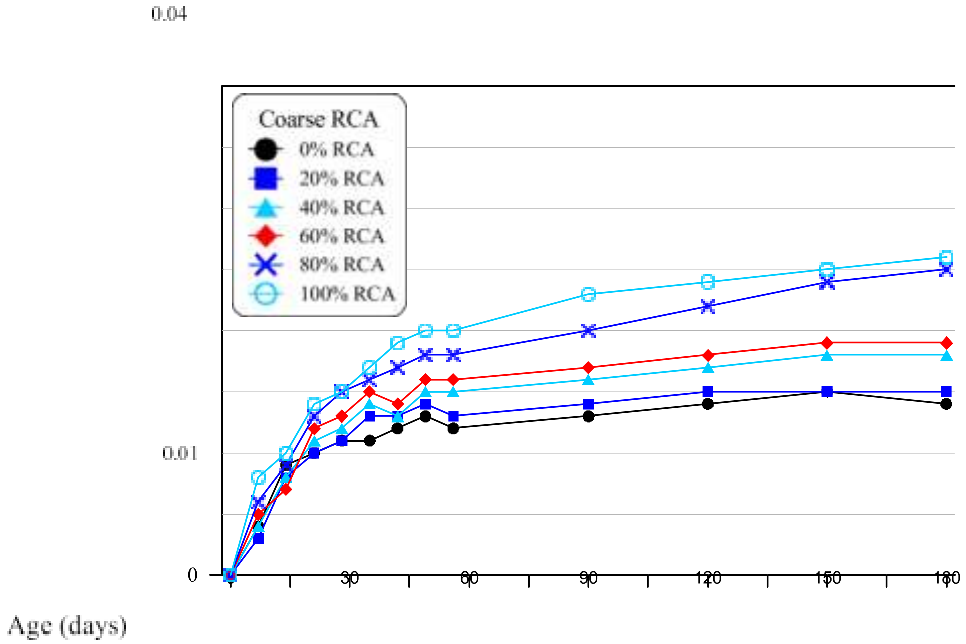


Fig. 15. Expansion with time for concrete with different contaminated coarse RCA contents.

SomestandardsprovidelimitsforsulfatecontentinaggregateexpressedasSO$_3$.Regardingnaturalaggregate,thislimitis0.5%forfineaggregateand0.1%forcoarseaggregateintheIraqistandards[34],whileASTMandEN standardsdonotprovide any limitations. The reason may be due to the absence of appreciable sulfates in the natural aggregate of their regions. However, the EN standard requires that the SO_3 content in recycled aggregate must not exceed 1%. On the other hand, researchers [9,35,36] have adopted the expansion strain to determine the quality of concrete made with gypsum contaminated aggregate even in all cases the SO_3 level in aggregate exceeds the standard limits. They reported that the concrete or mortar is acceptable whenever the expansion is not higher than 0.1% after one year of immersing in water or 0.05% after 6 months of immersing in water. In the present study, the expansion did not exceed0.048%inallcases,morepromisingresultswereachievedingroupsAandBwhereeithersandorgravel werepartiallyorfullyreplacedbyRCA.Other

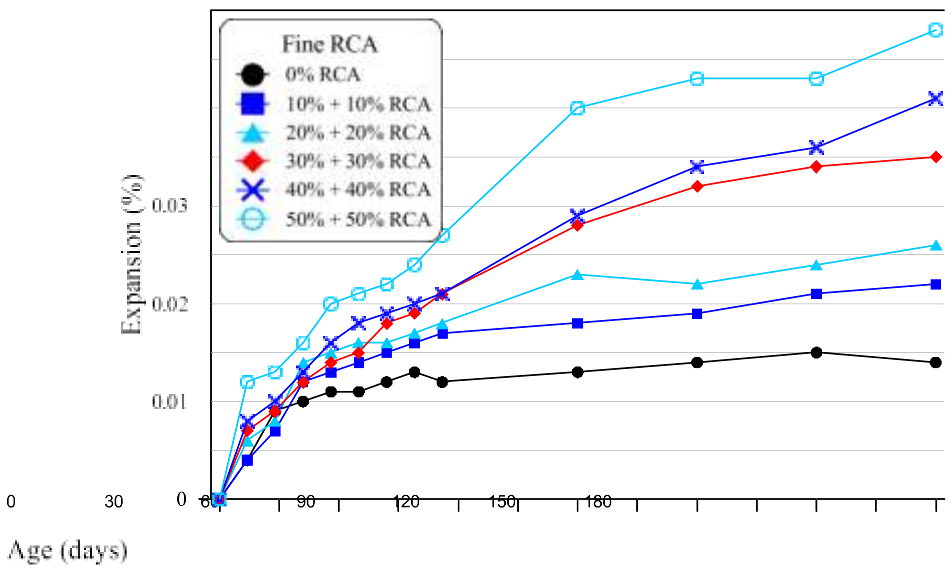


Fig. 16. Expansion with time for concrete with different contaminated mixed RCA contents.

studyalsosuggestedagreatpotentialforuseofcontaminatedrecycledaggregateinconstructionindustrythoug hthatstudy wasfocusedonexpansionofmortarsonly[9].

1.7. Effect of silicafume

Silica fume is a very reactive pozzolanic material because of its physical and chemical features. When using this by-[2]product material in concrete, a significant development in compressive and tensile strengths is expected. Figs. 17–19illustrate the influence of silica fume on the compressive strength, splitting tensile strength and modulus of rupture of concrete when sand, gravel and both of them were fully replaced by recycled fine (F), coarse (C) and mixed (M) RCA aggregates.Thefiguresshowcomparisonsbetweenthestrengthofconcretewith100%contaminatedRCAwit handwithoutthe10%cementsubstitutionbysilicafume.ThelittersSFinFigs.1719refertothepresenceofsilica fume.

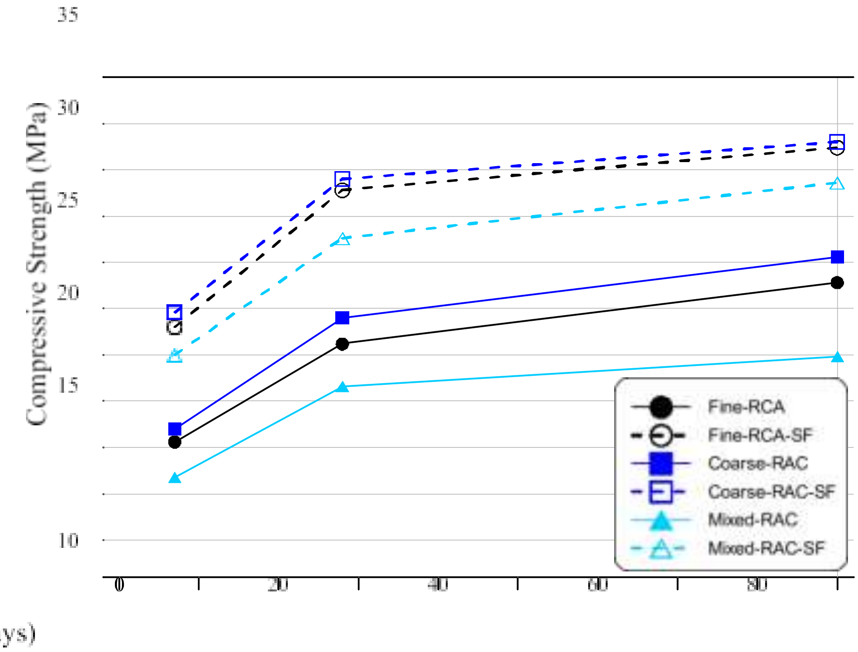


Fig. 17. Effect of silica fume on compressive strength of specimens with 100% RCA.

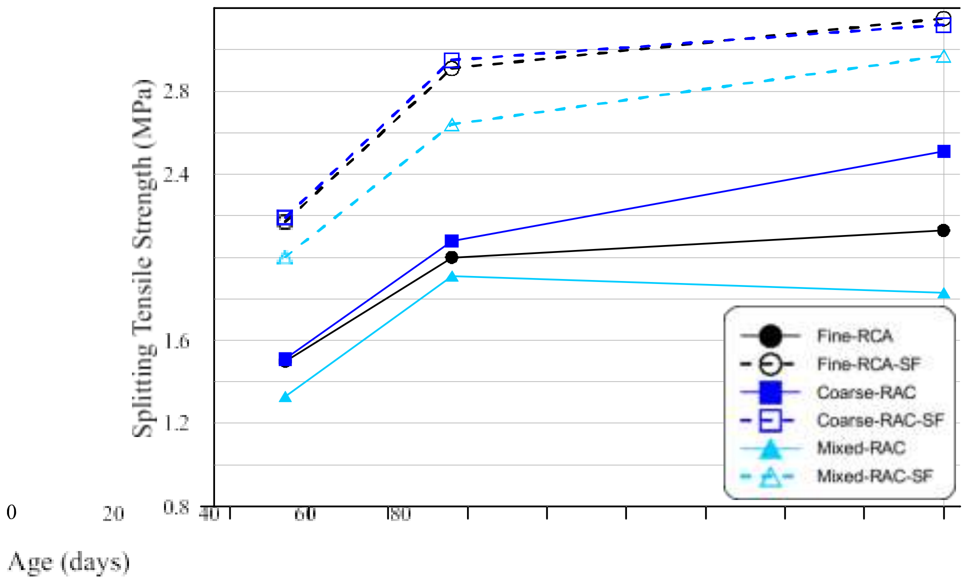


Fig. 18. Effect of silica fume on splitting tensile strength of specimens with 100% RCA.

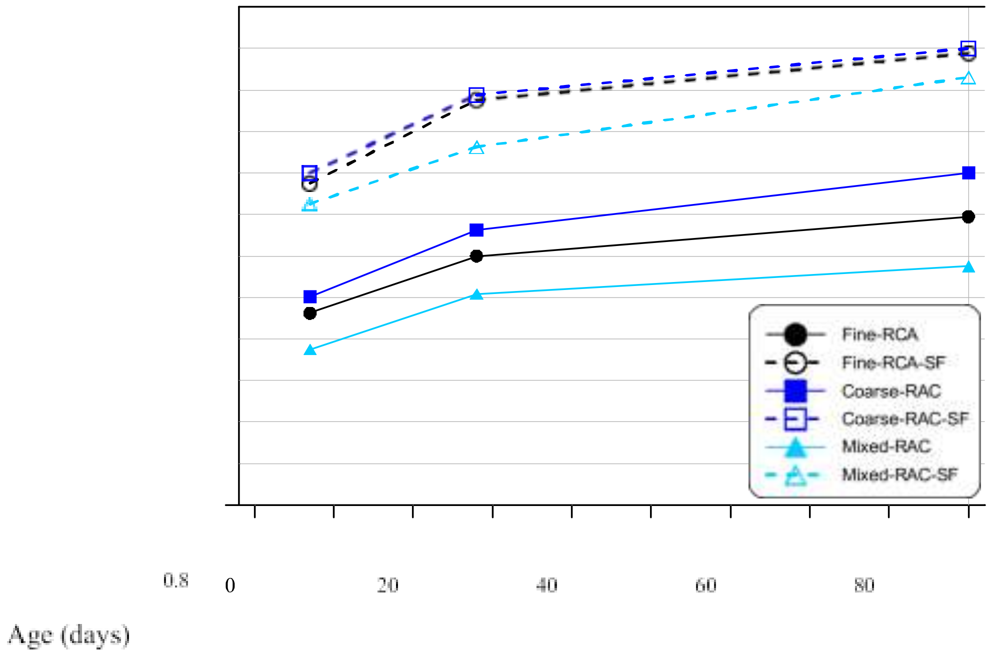


Fig. 19. Effect of silica fume on modulus of rupture of specimens with 100% RCA.

Figs. 17–19 show that the retained compressive strength, splitting strength and modulus of rupture weresignificantlyimprovedbytheadditionofsilicafume.Obviously,thesilicafumecompensatedforthestrengthreductioncausedbythe present of waste concrete aggregate such that both traditional concrete and that made with RCA showed almost similar strengths. The enhanced aggregate-matrix interfacial transition zone could be the reason behind such behavior because silicafumemakesthiszonedenserandstructurallystronger.Thepercentagedevelopmentincompressivestrengthduetosilicafumeadditionforthethreegroupswithfine,coarseandmixedcontaminatedRCAandforthethreeagesrangesfromapproximately25to50%.Similarly,thedevelopmentsinsplittingtensilestrengthandmodulusofrupturerangefrom24to62%and30to61%,respectively.Theresultsofthecurrentresearchareinconsistentwithpreviousresearches[37,38]thatshowedbetterstrengthanddurabilityperformanceofRCAspecimensincorporatedsilicafumecomparedtothosewithout silicafume.

V. CONCLUSIONS

1 Fromtheresultsoftheexperimentalworkconductedinthisstudy,thefollowingsconclusionscanbedrawn,

2 The compressive strength was lower with increasing the replacement level of virgin aggregate by contaminated RCA. However, the lowest strengths were recorded for Group C mixes in which the sand and gravel were replaced by contaminatedRCA,followedbyGroupAinwhichsandwasreplacedbycontaminatedRCA.Ontheotherhand,GroupB showedthebestresultsamongthethreegroupsofmixes.

3 The splitting tensile strength and flexural strength generally exhibited trend similar to compressive strength. The maximum reductions in splitting tensile strength due to the use of fine, coarse and mixed RCA were 35%, 33% and 39%, respectively,whiletheywere33%,28%and41%forflexuralstrength,respectively.

4 IncreasingthereplacementlevelofcontaminatedRCAledtoincreasetheexpansionstrainofconcreteofthethreegroups ofmixtures.However,thelargeststrainsweregenerallyobservedforGroupCmixesbecauseoftheirhighestSO_3content in aggregate, followed by group A and Group B. In all cases, the maximum recorded expansion was0.048%.

5 The use of silica fume counterbalanced the strength reduction and strain increment due to the replacementofnaturalaggregatebycontaminatedRCA.Thepercentagedevelopmentincompressive,tensileandflexuralstrengthsduetosilica fume inclusion ranged from 24 to62%.

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