Longitudinal Expansion of Reinforced Concrete Beams Subjected to Alkali-Silica Reaction

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ABSTRACT

Alkali silica reaction is the reaction between alkali in cement or other sources and certain forms of silica in aggregates. The reaction produces gel, which absorbs water and expands in volume, resulting in cracking and disintegration of concrete.

A laboratory study was carried out to investigate the effect of deleterious ASR expansion on the structural behavior of reinforced concrete beams and on mechanical properties of concrete cylinders made with the same concrete mixture. The specimens were made with reactive or non-reactive aggregates. All beams had 100×150mm cross-sectional areas and internal reinforcement. The beams were 1100mm long, and reinforced with different ratios of compression and tension steels. The beams were standard cured and then to simulate in-service conditions, fourteen beams were held under load that caused flexural cracking while being conditioned. Beams and concrete cylinders were kept under long-term observation at $38^{\circ} C$ and 100 percent relative humidity. During the long-term reaction period, concrete strain and steel strain were measured regularly.

The strain of concrete beams was measured along the compression and tension zones in the middle of the beams. Steel strains were monitored by strain gauges mounted on the middle of bars. It was quite clear that the beams containing reactive aggregate showed a significant increasing measured strain. Increase in compression steel with constant tension steel showed significant effective on tension expansion. On the contrary, an increase in tension steel with constant compression steel showed insignificant effective on compression expansion. The effect of ASR on mechanical properties and expansion of concrete cylinders was more significant than on expansion of reinforced concrete beams.

KEYWORDS

Alkali silica reaction (ASR); Expansion; Cracking; Reinforced concrete beams

1. INTRODUCTION

Many structures, such as dams, bridges and hydraulic structures, are suffering from deterioration induced alkali silica reaction that impair durability and might also affect the safety of installations. Some researchers investigated beams affected by ASR. [1-2-3-4-5-6]. In all research activities, ASR created large irreversible concrete and steel strains. But there are contradictory results of ASR effective on the overall serviceability, strength and stability of concrete structural members. In some papers, ASR- affected beams under load exhibited considerable losses of flexural strength [1]. Some papers indicated that even though the reactive reinforced beams experienced visible cracking due to ASR, their flexural loading capacity was nearly the same as that of the non-reactive aggregate beams [2,5]. A few articles showed that ASR increased the shear capacity of reinforced concrete beams [3]. This paper focuses on the new results obtained on the effects of ASR on longitudinal expansion of reinforced concrete beams.

2. EXPERIMENTAL PROGRAM

A. Constituent Materials

Type II Portland cement in accordance with ASTM standard was used. Aggregates used in Ostoor dam were chosen as reactive aggregates. This aggregate has been confirmed to be reactive by the accelerated mortar-bar

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ASTM C1260 test method. Figure1 shows that the expansion in both fine and coarse aggregate has exceeded the maximum allowable value of 0.2 percent. For comparison purposes, a non-reactive aggregate from suburb of Tehran was selected. The result of mortar-bar test is shown in figure2.

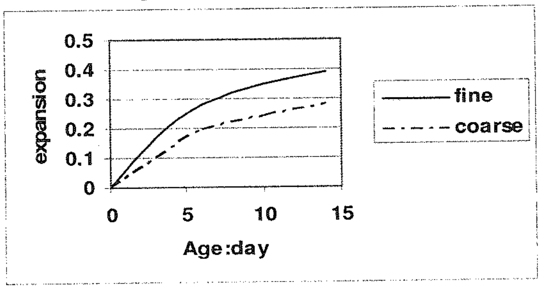

Figure1: Accelerated mortar-bar testing for reactive aggregate.

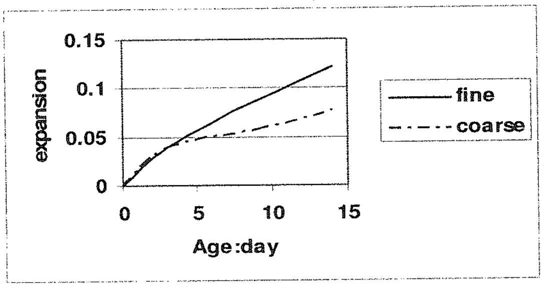

Figure2: Accelerated mortar-bar testing for non-reactive aggregate.

Type II steel bars with yield strength about 300 MPa were used for reinforcing the beams.

B. Test Specimens

Two concrete mixtures were produced. One with the reactive aggregate and the other with non-reactive one.Test specimens are listed in Table.1. Fourteen 1100mm long reinforced concrete beams were made, seven with the reactive aggregates concrete indicated by R, and seven with non-reactive aggregates concrete indicated by N. All beams had a 100×150mm rectangular cross section. Stirrups were placed in the shear span and other parts of all beams. Details of the beams are shown in figure3.

In addition, 100×100mm and 150×300mm concrete cylinders representive of concrete in the beams were also cast.The average strengths of the reactive and non-reactive aggregates concrete at 28 days were 25.6 and 26.2 MPa, respectively. The test specimens were kept in the casting forms for 1 day. After demolding, the specimens were standard cured. For length expansion measurements, studs were glued to the specimens as shown in figure4. A strain gauge mounted on the middle of each bar for monitoring steel strains.

Table 1:Test Specimens.

Concrete specimens		**Specimens size**	**Aggregate**	**Tension reinforcement**	**Compression reinforcement**	**NO. of specimens**
Beams	R1	100×150×1100 mm	Reactive	2 Φ 8	-	1
	N1		Non-reactive	2 Φ 8	-	1
	R2		Reactive	2 Φ 10	-	1
	N2		Non-reactive	2 Φ10	-	1
	R3		Reactive	2 Φ 12	-	1
	N3		Non-reactive	2 Φ 12	-	1
	R4		Reactive	2 Φ 10	2 Φ 8	1
	N4		Non-reactive	2 Φ 10	2 Φ 8	1
	R5		Reactive	2 Φ 12	2 Φ 8	1
	N5		Non-reactive	2 Φ 12	2 Φ 8	1
	R6		Reactive	2 Φ 12	2 Φ 10	1
	N6		Non-reactive	2 Φ 12	2 Φ 10	1
	R7		Reactive	2 Φ12	2 Φ 8	1
	N7		Non-reactive	2 Φ 12	2 Φ 8	1
concrete cylinders	R	100×100mm	Reactive	None	None	40
	N		Non-reactive	None	None	40
	R	150×300mm	Reactive	None	None	3
	N		Non-reactive	None	None	3

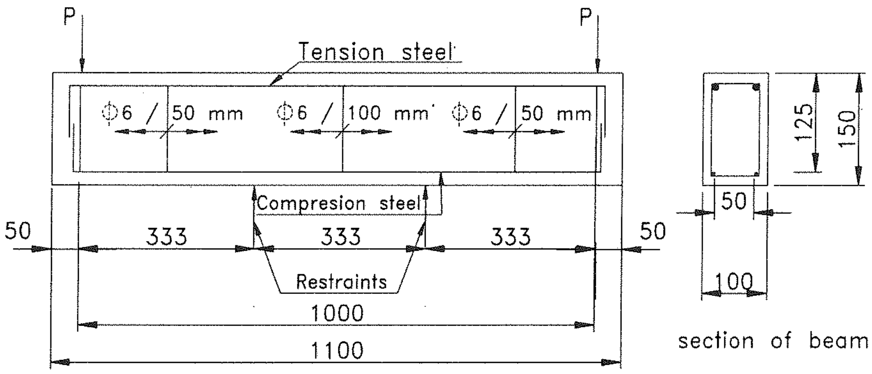

Figure 3: Reinforced concrete beams (dimensions are in mm).

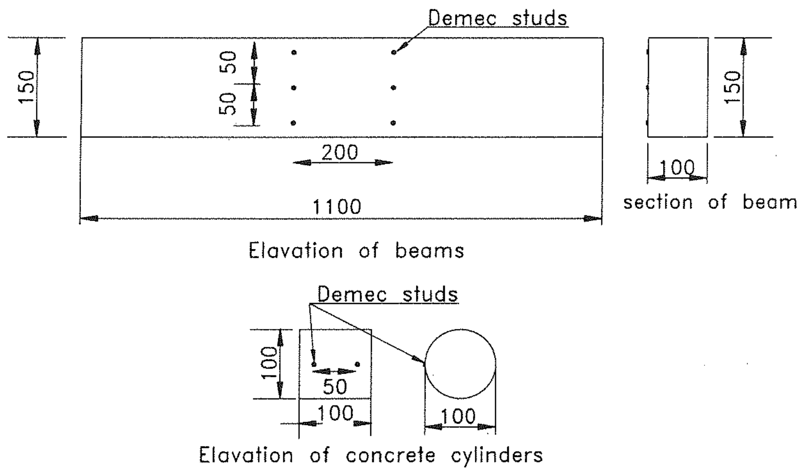

Figure 4: Arrangement of demec studs on specimens (dimensions are in mm).

C. Loading Condition

To investigate the ASR expansion of beams while under simulated service loads seven of two series of similar beams, the reactive aggregate beams and non-reactive aggregate beams were loaded. Two steel blocks with dimensions of 40×40×150mm were placed about 333mm apart in the center between the beams.

The loading was gradually increased by tightly fastening the screws on steel rods until cracks appeared having a width of about 0.2mm on the tension face of the beams. Details of loading are shown in figure5.

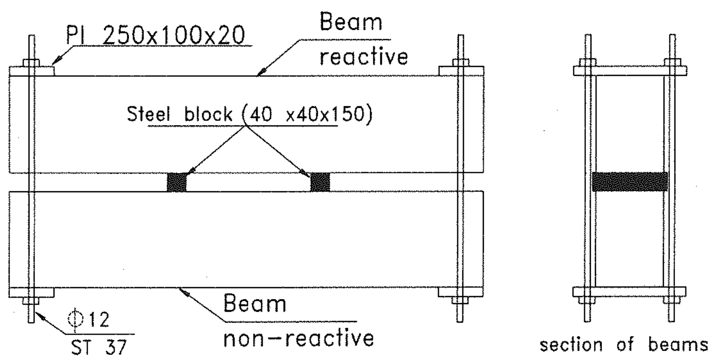

Figure 5: Details of loading.

D. ASR Accelerated Conditioning

The natural Na_2O_{eq} content was increased to 1.75% of the cement weight for reactive aggregate beams by adding sodium hydroxide solution into the mixing water.

A tank having dimensions of 600×600×3600mm was used for ASR accelerated conditioning.

All specimens except R7 and N7 were placed in the tank. In order to obtain 100 percent relative humidity, 60 mm depth of water was used at the bottom of tank. The water was heated to $38^{\circ}C$ by a temperature- controlled heater.

E .Creep Strain Measurement

For creep strain measurements, two R7, N7 beams were loaded and placed at laboratory environment. The concrete strain and steel strain of N7 beam were regularly monitored with time.

3. TEST RESULTS AND DISCUSSION

A. Concrete Strains

Concrete strains in reinforced beams are shown in figures 6 to 11.

It is clear from the figures that the strains are the same until 100 days and after that they are greatly increased in reactive aggregate beams due to alkali aggregate reaction. The strains are divided into the following three major parts:

1) Service load strain: This strain is approximately similar for both reactive aggregate beams and non-reactive aggregate beams.

2) Creep strain: This strain causes the increase in both tension and compression strains, regardless of whether in reactive aggregate beams or non-reactive aggregate beams.

3) ASR strain: This strain appears after 100 days just in reactive aggregate beams. It causes the increase in tension strain but the reduction in compression strain.

There is also minor increase in strains at initial days due to the increase in temperature and moisture absorption.

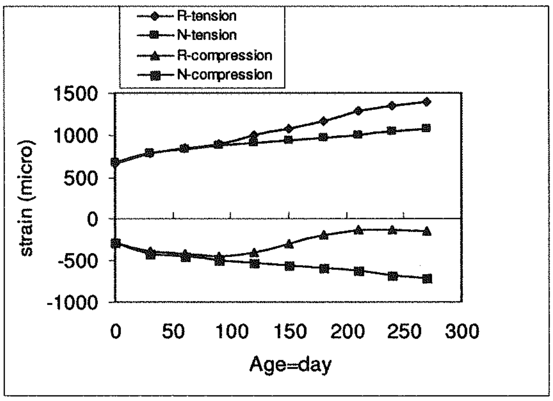

Figure 6: Strain variations of R1 and N1 concrete beams.

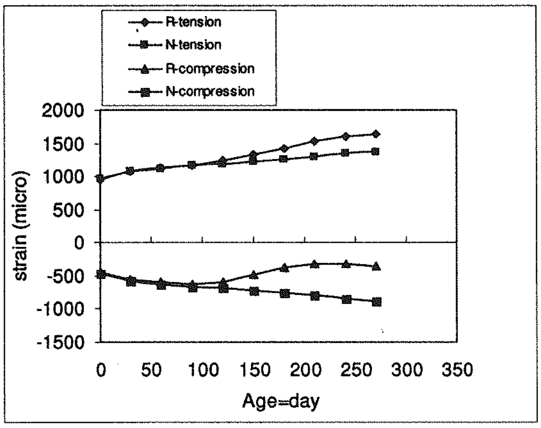

Figure 7: Strain variations of R2 and N2 concrete beams.

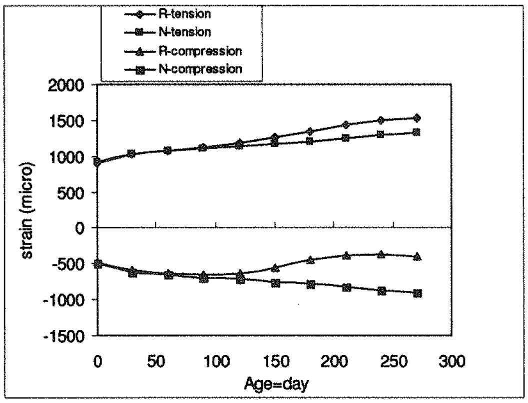

Figure 8: Strain variations of R3 and N3 concrete beams.

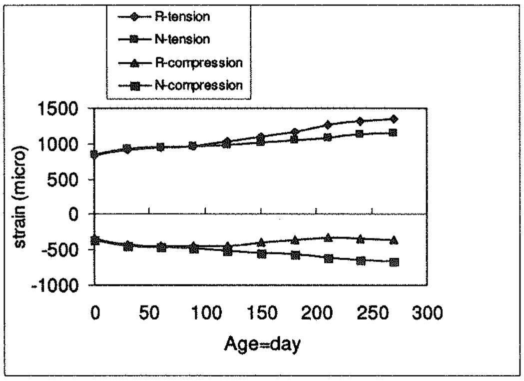

Figure 9: Strain variations of R4 and N4 concrete beams.

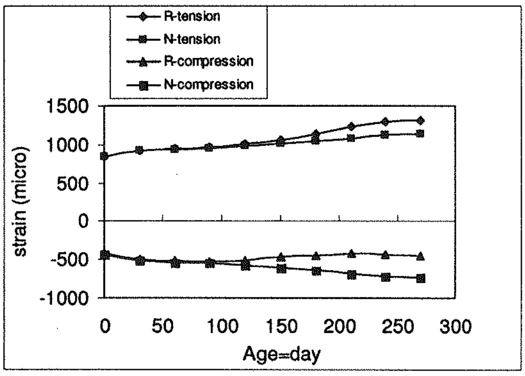

Figure 10: Strain variations of R5 and N5 concrete beams.

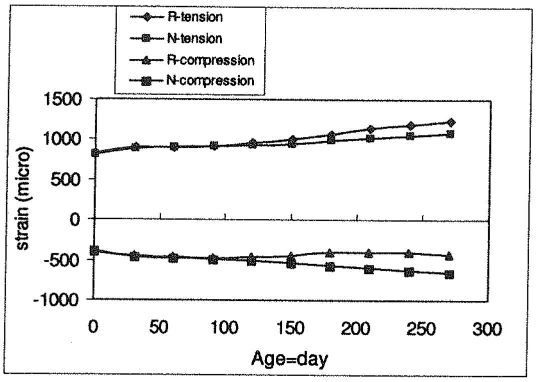

Figure 11: Strain variations of R6 and N6 concrete beams.

Table 3:ASR strain for R2 beam.

Age (day)	Concret e tension strain (micro)	Concrete compressio n strain (micro)	Steel tension strain (micro)	Steel compression strain (micro)
0	0	0	0	-
30	7	13	9	-
60	13	18	18	-
90	18	30	26	-
120	59	96	70	-
150	113	237	126	-
180	178	363	186	-
210	244	468	253	-
240	273	515	284	-
270	280	521	286	-

A schematic model of strain distribution is shown in figure12. The total measured strain is a combination of the elastic strain caused by the bending load, creep strain and tensile strain due to ASR. It is found from this figure that the neutral axis of the ASR affected beams has shifted towards the compression face. This is a very important structural implication indicating that the strain in the tension steel had also increased due to occurrence of ASR.

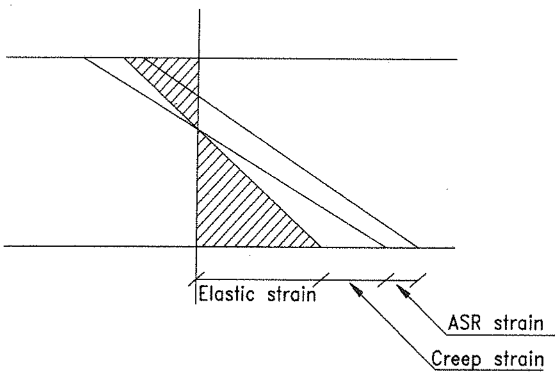

Figure 12: strain distribution.

B. ASR Strain

In order to obtain ASR Strain, the strains of non-reactive aggregate beams were subtracted from reactive aggregate beams. Concrete ASR strain and steel ASR strain are shown in Tables 2 to 7. It is clear that the ASR strain in compression zone is higher than tension zone because of more restraint from the tension reinforcement.

Table 2:ASR strain for R1 beam.

Age (day)	Concret e tension strain (micro)	Concrete compressio n strain (micro)	Steel tension strain (micro)	Steel compressio n strain (micro)
0	0	0	0	-
30	7	12	7	-
60	15	19	16	-
90	22	32	28	-
120	63	100	78	-
150	148	250	156	-
180	210	380	226	-
210	288	480	293	-
240	310	530	316	-
270	320	540	328	-

Table 4:ASR strain for R3 beam.

Age (day)	Concret e tension strain (micro)	Concrete compressio n strain (micro)	Steel tension strain (micro)	Steel compressio n strain (micro)
0	0	0	0	-
30	7	13	7	-
60	12	16	15	-
90	17	28	22	-
120	48	79	58	-
150	93	201	102	-
180	143	330	156	-
210	199	440	210	-
240	213	493	223	-
270	221	503	230	-

Table 5:ASR strain for R4 beam.

Age (day)	Concret e tension strain (micro)	Concrete compressio n strain (micro)	Steel tension strain (micro)	Steel compressio n strain (micro)
0	0	0	0	0
30	7	6	7	7
60	15	13	15	16
90	16	19	22	24
120	52	60	59	69
150	90	135	98	141
180	128	193	135	201
210	193	263	201	276
240	211	290	220	302
270	220	300	225	309

Table 6:ASR strain for R5 beam.

Age (day)	Concret e tension strain (micro)	Concrete compressio n strain (micro)	Steel tension strain (micro)	Steel compressio n strain (micro)
0	0	0	0	0
30	7	7	6	9
60	9	11	13	16
90	15	16	24	22
120	38	53	46	54
150	53	129	63	126
180	100	180	106	183
210	150	243	156	246
240	176	278	183	283
270	185	283	193	290

Table 7:ASR strain for R6 beam.

Age (day)	Concret e tension strain (micro)	Concrete compressio n strain (micro)	Steel tension strain (micro)	Steel compressio n strain (micro)
0	0	0	0	0
30	7	7	5	10
60	9	9	13	16
90	13	13	21	23
120	33	43	40	42
150	50	83	56	63
180	87	154	96	98
210	111	203	120	126
240	131	225	141	146
270	143	232	145	151

C. Effect of Increase in Tension Steel on ASR Strain

Effect of increase in tension steel on ASR strain is shown in figure13. When the tension steel is increased, (with constant compression steel) it causes the reduction in ASR strain at tension zone of concrete. In R2 and R3 beams, there are 12.5% and 31% reduction in strain, respectively, when compared with R1 beam. Large differences in concrete strains between the tension and compression zone of beams can be developed due to ASR expansion. This difference shows that the increase in tension steel with constant compression steel has insignificant influence on ASR strain at Compression zone. There are 3.5% and 6.8% reduction when compared with R1 beam in R2 and R3 beams, respectively.

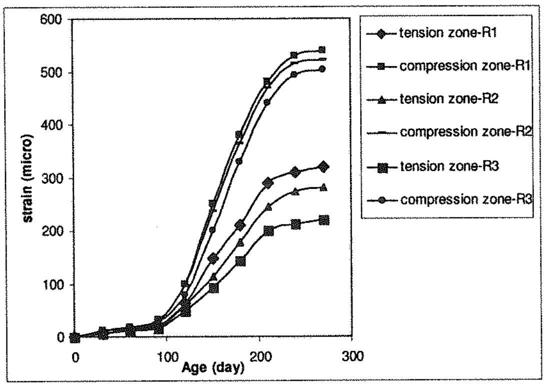

Figure 13: Effect of increase in tension steel on ASR strain.

D. Effect of Increase in Compression Steel on ASR Strain

Figure14 shows the effect of increase in compression steel on ASR strain. When the compression steel is increased (with constant tension steel) ASR strain in compression zone is reduced.

In R5 and R6 beams, there are 43.7% and 53.8% reduction in strain, respectively, when compared with R3 beam. There is significant influence on ASR strain at tension zone, while compression steel (with constant tension steel) is increased. There are 16.3% and 35.3% reduction with compared with R3 beam in R5 and R6, respectively due to the increase in compression steel.

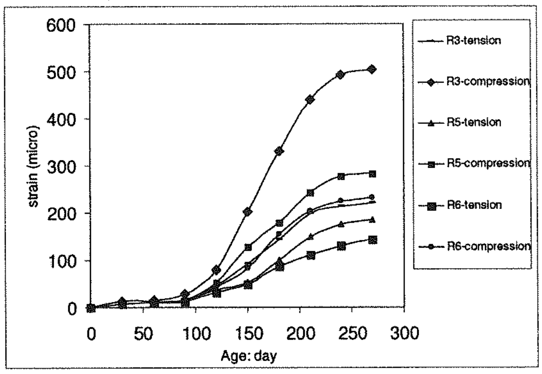

Figure 14: Effect of increase in compression steel on ASR strain.

E. Mechanical Tests of Concrete Cylinders

Expansion of reactive and non-reactive concrete cylinders is shown in figure15. After 240 days the strain in reactive concrete cylinder has reached about 1050 microstrain. Compressive strength and nondestructive dynamic modulus tests in accordance with ASTM C215-91 [7] were carried out at laboratory. The variations of compressive strength ratio to the 28 day value and variations of the dynamic modulus ratio to the 28 day value are shown in figure16. It was found that the change in the mechanical properties was closely related to ASR expansion. The compressive strength and dynamic modulus were not affected significantly up to 100 days. At an age of 240 days, the losses of the compressive strength and dynamic modulus of the concrete cylinders were 28 and 34 percent, respectively, compared with the corresponding 28 day values.

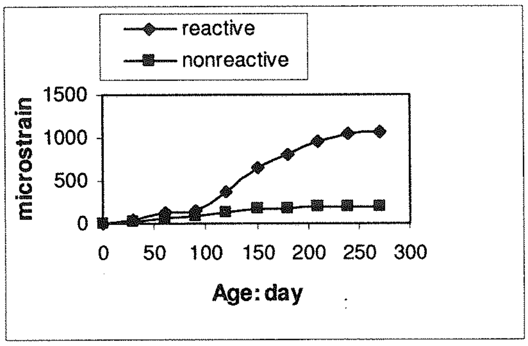

Figure 15: ASR strain of concrete cylinders.

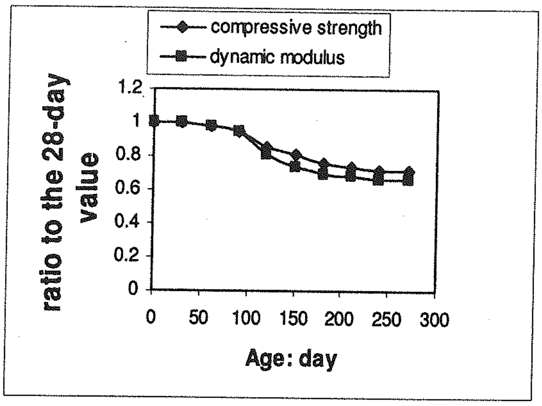

Figure 16: Change in mechanical properties of reactive concrete cylinders.

4. CONCLUSIONS

From the results obtained in this investigation, the following conclusions can be drawn:

1. Expansion of ASR in tension zone of beams is less than compression zone due to the more restrain from the tension reinforcement.
2. The neutral axis of the beams shifted towards the compression face due to ASR.
3. Due to large differences in concrete strains between the tension and compression zone of beams, influence of the increase in tension steel with constant compression steel is insignificant on compression zone.
4. Influence of increase in compression steel with constant tension steel on tension zone is significant.
5. Mechanical properties of concrete cylinders are closely related to ASR expansion. At an age of 8 months, the compressive strength and dynamic modulus were reduced by 28 and 34 percent, respectively, compared with the corresponding 28-day values.
6. ASR shows a much more detrimental effect on the mechanical properties and expansion of concrete cylinders than on expansion of reinforced concrete beams.

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