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Durability of Crushed Brick Aggregate Concrete in Regions Susceptible to Frost

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***Abstract:** Crushed brick coarse aggregates have proved to be satisfactory as regards mechanical properties but have not at all been investigated for durability. Brick aggregates are a suitable structural material in areas with scarce natural aggregates. This paper describes an investigation carried out to assess the frost resistance of concrete with different types of brick aggregates varying from low strength, high absorption brick aggregates to high strength, low absorption brick aggregates. A wide range of w/c ratios were investigated ranging from 0.63 to 0.29. Brick aggregates used in this investigation were obtained by crushing normal construction bricks, sand lime bricks and engineering bricks.*

The RILEM 4-CDC method was used for frost resistance tests. Surface absorption was also investigated. Supplementary tests were carried out on the bricks to determine the pore size, saturation, drying, and freeze/thaw behavior so that aggregate and concrete performance can be correlated. Concrete with normal construction brick aggregates was observed to be highly frost susceptible showing significant expansion and large reductions in dynamic modulus when subjected to cyclic freezing and thawing. Concrete with sand lime brick aggregates was found to have better frost resistance compared to concrete with gravel aggregate with negligible loss in dynamic modulus in spite of some expansion. The behavior of concrete with engineering brick aggregates was found to be almost similar to gravel concrete control.

Keywords: Sustainable construction, Recycled aggregates, Crushed Brick waste, Frost Resistance

I. INTRODUCTION

Exposure of damp concrete to alternate cycles of freezing and thawing is a severe test of concrete quality. Poor quality concretes are certain to fail after a small number of cycles whereas good quality concrete may be undamaged or little damaged after a large number of freezing and thawing cycles. However even very good quality concrete may suffer damage from cyclic freezing under extreme conditions such as when in a saturated or nearly saturated state. Properly proportioned, placed, finished and cured air entrained concrete may resist cyclic freezing and thawing over a long period of time.

Bricks undergo reversible expansion and contraction due to wetting and drying, respectively. In addition, there is larger irreversible expansion taking place over a long period of time. This is greater on the first day and reduces subsequently reaching a limiting value after approximately six months. Typical values for linear moisture expansion strains for a 0.229m long brick, after four months, range from 0.02 to 0.07%. Dimensional changes in clay bricks may also occur due to thermal expansion/contraction. Average values for the coefficient of thermal expansion of clay bricks lies within the range of 3.6 to 5.8*10-6 per C as compared to 11 to 16*10-6 per C for Portland cement pastes and 5 to 13*10-6 per C for various rocks forming aggregates. Bricks are characteristically brittle, and their stress/strain relationship remains almost linear up to the point of fracture. Strain at fracture is always around 10 whereas stress at fracture can vary over a wide range i.e. failure stress/Young's modulus is approximately 10-3. Young's modulus of bricks ranges from 3.5 kN/mm2 for low strength bricks to 34 kN/mm^2 for high strength bricks. Under static loads, bricks show little or no plastic deformation prior to failure but under small alternating stresses, well below those which would cause fracture, bricks show considerable plastic or irreversible strains. Under burnt bricks are lighter in color and lower in strength. The weight of bricks can be reduced by the presence of more voids in bricks or due to inadequate compaction of the raw meal before burning to form brick. Sandlime bricks are made from a mixture of lime and sand. Engineering bricks are very strong and durable and are used in engineering works like piers, bridges etc. Durability of bricks is a function of their resistance to frost action and moisture penetration. Fracture in bricks occur if the elastic resilience of the brick cannot accommodate the expansion of freezing water. Repeated freezing and thawing cycles accelerate the disruptive effect on brick.

II. RESEARCH SIGNIFICANCE

This research investigates the frost resistance of concrete with various types of crushed brick coarse aggregates. Crushed brick aggregates have proved to be satisfactory as regards mechanical properties but have not at all been investigated for frost resistance. Brick aggregates are a suitable structural material in areas with scarce natural aggregates.

III.DESCRIPTION OF TESTS

Three types of bricks were selected for testing frost resistance of brick aggregate concrete. They were normal construction bricks, sand lime bricks and engineering bricks. Table 1 gives the properties of bricks. Table 2 gives the properties of crushed brick coarse aggregates obtained by manually crushing the bricks to a maximum size of 37.5mm.

W/C ratios of 0.63, 0.50, 0.385 and 0.296 which were observed to be equivalent to characteristic strengths of 20.7, 35, 50 and 65N/mm^2 were investigated. Concrete with normal construction brick and sand lime brick aggregates was investigated for w/c ratios of 0.63 and 0.50 since further lowering of w/c ratio did not increase the compressive strength of concrete. The w/c ratio was kept constant so that there was no variation in the paste characteristics and merely aggregates were changed from gravel to different types of crushed brick coarse aggregates. Maintaining a constant w/c ratio facilitated comparative study, especially on durability of different concretes due to change of aggregates only whilst all other aspects were mostly kept constant. Table 3 gives the quantities used for different mixes. In order to understand the freezing and thawing behaviour of concrete with brick aggregates, following tests were also carried out to investigate the behaviour of different types of bricks to saturation, drying, freezing and thawing:

1) The expansion and contraction on saturation and drying, respectively, of different types of bricks.
2) Freezing and thawing behavior of bricks investigated by freezing three bricks of each type and then thawing. The bricks were saturated in water for twenty-four hours, wrapped in heavy duty polyethylene, sealed and then frozen to -10^0 C in sixteen hours. Thawing was then carried out for eight hours at 20^{0}C. Length measurements were taken after saturation, freezing and thawing.
3) To assess the pore sizes in bricks, capillary rise test was carried out.

Initial surface absorption tests were carried out on all the samples to assess the surface absorption of concrete with brick aggregates.

The RILEM 4 CDC method of testing frost resistance of concrete was selected for carrying out testing on brick aggregate concrete. Although sensitive to initial moisture content of the specimen, it has the advantage of more realistic freezing and thawing rates and surrounding conditions as compared to other methods along with requiring simple freezing equipment for testing. 100*100*500mm prismatic specimens were wrapped in heavy duty polyethylene and sealed before they were subjected to cyclic freezing and thawing. Samples were frozen to -10^0 C at a rate of 3.5^{0}C/hour for 16 hours. Thawing was carried out by raising the temperature of the cooling cabinet to 20^0 C with the help of a small fan heater, for 8 hours. Samples were only removed from the cabinet for taking the readings. The centre of samples cooled down to -10^0 C at the end of freezing and reached a minimum of 5^{0}C at the end of thawing period. One cycle per day of freezing and thawing was used. Length, weight and resonant frequencies were monitored to assess the frost damage after every ten cycles for a total of 50 cycles

IV.DISCUSSION OF RESULTS

A. *Performance of bricks*

It was observed that normal construction bricks show an average expansion on saturation and contraction on drying of 0.035% whereas sandlime bricks show average expansion/contraction of 0.015% and engineering bricks show an average of 0.02%. In freezing and thawing of bricks, average shrinkage of 0.0058% was observed for normal construction bricks and 0.026% for sandlime bricks. All normal construction bricks cracked at the center on freezing. Engineering bricks were observed to expand by an average value of 0.006%. Results obtained from the capillary rise tests are given in Table 4

B. *Initial surface absorption*

This test was carried out in accordance with BS 1881: Part 5: 1970. Table 5 gives the details of ISAT tests carried out on 150mm cubes of concrete with different aggregates.

C. *Performance of concrete with crushed brick aggregates*

Tables 6 to 9 give the detailed performance of different concretes when subjected to frost resistance test. Figures 1 and 2 show the variation of dynamic modulus and length, respectively, with the number of freezing and thawing cycles.

1) *Concrete with normal construction brick aggregate* started expanding continuously and large expansions resulted in rapid decrease in dynamic modulus as shown in Figures 1 and 2. For w/c ratio of 0.63, increase in length after 50 cycles was observed to be 0.2177% and the corresponding reduction in dynamic modulus was 29% as shown in Table 6. For w/c ratio of 0.50, increase in length at the end of 50 cycles was 0.01% and corresponding reduction in dynamic modulus was 7%. There was slight decrease in length in first thirty cycles after which the length again started increasing as shown in Figure 2 showing the frost proneness of concrete. The large increase in length and rapid reduction in dynamic modulus of normal construction brick aggregate concrete is due to the high absorption of about 20% of these aggregates. When the bricks from which these

aggregates are obtained were subjected to freezing and thawing all the bricks cracked on first freezing only. Capillary rise test on normal construction bricks revealed that these bricks had large pore sizes in the range of 100 to 1,000nm, hence large pores have a larger amount of freezable water. Since the specimen were fully saturated on start of testing, expansion of water in the aggregates on freezing pressurised excess water out of the aggregate into the surrounding mortar. On further cooling, this water expands and exerts dilative pressures on the mortar resulting in microcracking within the mortar, along the bond surface between mortar and aggregate particles and also within the aggregate particles. Cyclic freezing and thawing tends to increase the microcracking thereby resulting in loss of strength along with length increases. The increase in length as well as reduction in dynamic modulus of concrete with normal construction brick as aggregate are much higher as compared to normal concrete rendering this type of concrete highly susceptible to frost damage. Due to the presence of 2375ppm of chlorides and similar quantity of sulphates in normal construction brick aggregates, observed during the tests for sulphate and chloride content of aggregates, on freezing of water in pores of the aggregate, increased concentration of salts in the unfrozen solution attracts more water thereby increasing the disruptive action of cyclic freezing and thawing.

2) *Concrete with sand lime brick aggregate* shows some contraction before expanding as shown in Figure 2. For w/c ratio of 0.63, increase in length after 50 cycles was observed to be 0.045% and the corresponding reduction in dynamic modulus was 0.75% as shown in Table 7. For w/c ratio of 0.50, increase in length at the end of 50 cycles was 0.07% and corresponding reduction in dynamic modulus was 1.14%. There was slight contraction in first twenty cycles after which slight expansions took place as shown in Figure 2. The small increase in length and negligible reduction in dynamic modulus of sand lime brick aggregate concrete is due to the presence of fine capillaries varying from 10 to 100nm in diameter thereby leaving little amounts of freezable water in the pores. When the bricks from which these aggregates are obtained were subjected to freezing and thawing an average value of 0.0048% of shrinkage was observed. Concrete with sand lime brick aggregates showed negligible loss of dynamic modulus as compared to normal concrete although expansions were higher. The very low loss in dynamic modulus is possibly due to similar amounts of expansions/contractions in aggregates as well as mortar, thereby preventing microcracking within the aggregates as well as in the mortar and the interface between mortar and aggregate.

3) *Concrete with engineering brick aggregate* also shows slight contraction before expanding as shown in Figure 2. For w/c ratio of 0.63, increase in length after 50 cycles was observed to be 0.05% and the corresponding reduction in dynamic modulus was 8.3% as shown in Table 8. For w/c ratio of 0.50, increase in length at the end of 50 cycles was 0.04% and corresponding reduction in dynamic modulus was 11.5%. For w/c ratio of 0.385, increase in length at the end of 50 cycles was 0.05% and corresponding reduction in dynamic modulus was 9.11%. For w/c ratio of 0.296, increase in length at the end of 50 cycles was 0.046% and corresponding reduction in dynamic modulus was 6%. The small increase in length and reduction in dynamic modulus of engineering brick aggregate concrete is due to the presence of fine capillaries varying from 10 to 100nm in diameter reducing the amounts of freezable water in the pores. When the bricks from which these aggregates are obtained were subjected to freezing and thawing, an average value of 0.006% of expansion was observed. The reduction in dynamic modulus along with expansion and contraction on cyclic freezing is somewhat similar to normal concrete, with slight variations.

4) *Normal Concrete* showed slight contraction before expanding. Table 9 gives the performance of normal concrete in the frost resistance test. For w/c ratio of 0.63, increase in length after 50 cycles was observed to be 0.0095% and the corresponding reduction in dynamic modulus was 10.95%. For w/c ratio of 0.50, increase in length at the end of 50 cycles was 0.048% and corresponding reduction in dynamic modulus was 7.33%. For w/c ratio of 0.385, increase in length at the end of 50 cycles was 0.071% and corresponding reduction in dynamic modulus was 14.39%. For w/c ratio of 0.296, increase in length at the end of 50 cycles was 0.035% and corresponding reduction in dynamic modulus was 0%.

V. CONCLUSIONS

Concrete with normal construction brick aggregates is highly frost susceptible and shows significant expansions along with large reductions in dynamic modulus when subjected to cyclic freezing and thawing. Concrete with sand lime brick aggregates has better frost resistance as compared to normal concrete with similar w/c ratio, since there is negligible loss in dynamic modulus in spite of some expansion on cyclic freezing. Concrete with engineering brick aggregates behave somewhat similar to normal concrete when subjected to cyclic freezing and thawing.

S/NO	TYPE OF BRICK	CRUSHING STR	ABSORPTION	DENSITY
1.	Normal brick	19.54N/mm^2	23.245%	1292.8kg/m^3
2.	Sandlime brick	15.39N/mm^2	14.808%	1721.5kg/m^3

3.	Engineering brick	40.25N/mm^2	6.395%	1872.2kg/m^3

Table 1: Properties of bricks

TYPE	RELATIVE DENSITY SSD	BULK DENSITY kg/m^3		IMPACT VALUE	10% FINES VALUE kN	ABSORPTION %
		uncompacted	compacted			
Normal brick	1.8592	839.720	900.710	46.065	59.85	19.6
Sand lime brick	2.3325	1011.35	1093.62	45.695	40.76	9.55
Engineering brick	2.3164	1126.24	1263.12	31.610	144.3	2.76
Normal Aggregate	2.4900	1560.99	1738.30	22.960	391.0	1.05

Table 2: Properties of brick aggregates

MIX	W/C RATIO	CEMENT	WATER	SAND	AGGREGATE	SLUMP
		Kg	kg	kg	kg	
Sample 1: Normal Brick						
LBC/63	0.63	305	190	530	1030	30-60mm
	0.50	380	190	475	1005	30-60mm
Sample 2: Sand lime brick						
SBC/63	0.63	305	190	590	1145	30-60mm
	0.50	380	190	535	1130	30-60mm
Sample 3: Engineering brick						
EBC/63	0.63	305	190	580	1125	30-60mm
	0.50	380	190	520	1100	30-60mm
	0.385	495	190	455	1060	30-60mm
Design	0.296	695	205	430	875	60-180mm
Actual	0.296	775	230	395	800	60-180mm
Sample 4: Normal Aggregate						
GC/63	0.63	255	160	650	1260	30-60mm
	0.50	320	160	590	1260	30-60mm
	0.385	415	160	525	1225	30-60mm
Design	0.296	590	175	515	1045	60-180mm
Actual	0.296	695	205	465	960	60-180mm

Table 3. Mix design for maximum aggregate size 37.5mm

SAMPLE	CAPILLARY RISE	MEAN PORE SIZE
Normal brick	Average 18mm	1243.2rA^0 i.e.100 to 1000nm
Sandlime brick	Average 5mm	437.5rA^0 i.e. 10 to 100nm
Engineering brick	Average 8mm	707.5rA^0 i.e. 10 to 100nm

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Table 4. Results of capillary rise test on bricks

SAMPLE NO.	MIX	ISAT RESULTS (ml/m^2/s)		
		10MIN	30MIN	1HOUR
1. Normal brick	LBC/63	63.00	29.50	9.25
aggregate concrete	LBC/50	34.50	17.50	7.00
2. Sand lime brick	SBC/63	47.00	16.00	8.00
aggregate concrete	SBC/50	22.00	12.00	6.00
3. Engineering brick	EBC/63	25.25	13.00	6.50
aggregate concrete	EBC/50	14.00	8.25	5.00
	EBC/385	8.50	6.50	3.50
	EBC/296	6.00	4.00	2.50
4. Normal concrete	GC/63	19.50	14.00	9.00
	GC/50	15.00	7.00	5.00
	GC/385	8.00	5.00	4.00
	GC/296	5.00	4.25	3.00

Table 5. Results of ISAT tests

Sample No 1. Normal construction brick aggregate concrete
W/C Ratio 0.63
Observations

Cycles	Start	10	20	30	40	50
Length(*0.01mm):	276.8	296.5	331.67	348.5	350.67	385.67
Weight(g):	10691	10683.7	10653	10651.3	10652.3	10648
R frequency(Hz):	3255.7	2928	2818.5	2762.67	2757.3	2741.3
Dyn.Mod.(N/mm^2):	22663	18331.9	16956	16305.2	16245.1	16073

Reduction in dyn mod = 29%, Increase in length = 0.2177%

Sample No 1. Normal construction brick aggregate concrete
W/C Ratio 0.50
Observations

Cycles	Start	10	20	30	40	50
Length(*0.01mm):	313.6	300	300.8	301.6	302.17	308.3
Weight(g):	11026	11041	11041	11043	11046.3	11059.7
R frequency(Hz):	3515	3433	3420	3390	3389	3386
Dyn.Mod.(N/mm^2):	27251	26011	25815	25369	25362.4	25354.4

Reduction in dyn.mod.= 6.96%, Decrease in length = 0.01%

Table 6. Frost resistance test on concretes with normal brick aggregate.

Sample No 2. Sandlime brick aggregate concrete
W/C Ratio 0.63
Observations

Cycles	Start	10	20	30	40	50
Length(*0.01mm):	241.5	249	235.75	240.5	249.75	263.7
Weight(g):	11030.5	11034	11034.5	11034	11034	11034

R frequency(Hz):	3458.5	3447	3447.5	3445	3445	3443.5
Dyn.Mod.(N/mm^2):	26387.5	26229	26223.5	26189	26199.5	26191
Reduction in dyn. mod.= 0.75%, Increase in length = 0.045%						

Sample No 2. Sandlime brick aggregate concrete W/C Ratio 0.50 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm):	293.6	271	257.83	256.17	258.6	256.67
Weight(g):	11162	11161	11164.7	11164.7	11166	11167
R frequency(Hz):	3543	3533	3526	3524.67	3525.6	3525
Dyn.Mod. (N/mm^2):	28028	27838	27721.6	27698.9	27710	27710.3
Reduction in dyn.mod. = 1.14%, Decrease in length = 0.07%						

Table 7. Frost resistance test on concretes with sand lime brick aggregate.

Sample No 3. Engineering brick aggregate concrete W/C Ratio 0.63 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm):	290.67	259	263.17	265	265.2	265.8
Weight(g):	11980	11981	11972	11983	11985	11989
R frequency(Hz):	3660.3	3606.3	3521.6	3518	3513	3505
Dyn.Mod.(N/mm^2):	32101	31120	29649	29630	29552	29433
Reduction in dyn.mod. = 8.3%, Decrease in length = 0.05						

Sample No 3. Engineering brick aggregate concrete W/C Ratio 0.50 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm):	314.5	289.5	285.8	290.33	292.67	293.33
Weight(g):	11383	11388	11396	11397	11398	11398
R frequency(Hz):	3570	3412	3407	3390	3379	3357.6
Dyn.Mod.(N/mm^2):	29015	26488	26426	26169.7	26004.9	25678
Reduction in dyn.mod. = 11.49%, Decrease in length = 0.042%						
W/C Ratio 0.385 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm):	271.17	248	262.17	264.17	269.2	297.2
Weight(g):	11951.2	11947	11946.3	11949.7	11955	11994
R frequency(Hz):	3385.3	3325.6	3263.3	3261.17	3227	3220
Dyn.Mod.(N/mm^2):	27392.7	26832	25434.4	25410.4	24901	24897
Reduction in dyn.mod. = 9.11%, Increase in length = 0.052%						

Sample No 3. Engineering brick aggregate concrete W/C Ratio 0.296 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm):	251.67	266.83	243.5	245.83	270.5	274.5
Weight(g):	11332	11333	11335	11335.7	11338.3	11367
R frequency(Hz):	3392	3305	3296	3288	3286	3282.7
Dyn.Mod.(N/mm^2):	26077	24773	24620	24504.2	24504.2	24512
Reduction in dyn.mod. = 6%, Increase in length = 0.046%						

Table 8. Frost resistance test on concrete with engineering brick aggregate.

Sample No 4 Normal W/C Ratio 0.63 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm):	273.9	252.92	259.5	262.83	265.5	278.67
Weight(g):	12424	12425.7	12426	12426.5	12428	12428.7
R frequency(Hz):	4546	4432.67	4360	4351	4319	4288.67
Dyn.Mod.(N/mm^2):	51352	48788.4	47215	47088.8	46349	45728
Reduction in dyn.mod. = 10.95%, Increase in length=0.0095%						
W/C Ratio 0.50 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm):	272.67	257.8	250.8	250.3	249.8	248.5
Weight(g):	12634.3	12642	12643	12646.3	12646	12654.3
R frequency(Hz):	4612.3	4553	4542.67	4530.67	4501	4438.67
Dyn.Mod.(N/mm2):	53754.7	52382	52134.2	51855	51192	49814.3
Reduction in dyn.mod.= 7.33%, Decrease in length = 0.048%						
W/C Ratio 0.385 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm):	245.83	228.83	240	240	252.5	281.3
Weight(g):	12218	12178.7	12213	12212.3	12214.7	12220
R frequency(Hz):	4377.3	4243.67	4198	4193.7	4173.3	4047
Dyn.Mod.(N/mm2):	46821	43820.9	43035	42945.8	42558.7	40085
Reduction in dyn.mod.= 14.39%, Increase in length = 0.071%						
W/C Ratio 0.296 Observations						
Cycles	Start	10	20	30	40	50
Length(*0.01mm):	233	248.3	224	226.17	244.8	250.7
Weight(g):	12131.2	12133.3	12133	12134.3	12136	12138
R frequency(Hz):	4352.3	4358.67	4358	4357	4358	4358
Dyn.Mod.(N/mm2): 45959.1		46129.9	46070	46057.6	46116	46137

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Reduction in dyn.mod.= 0%, Increase in length = 0.035%

Table 9. Frost resistance test on normal concrete.

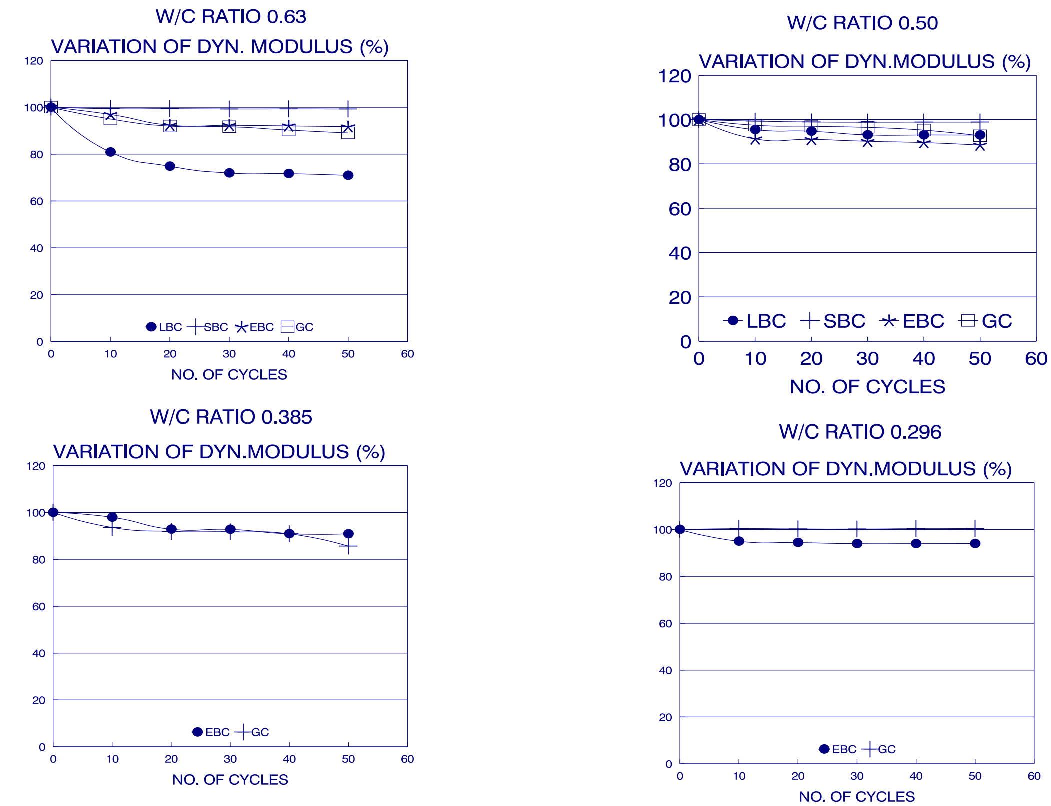

Figure 1. Variation of dynamic modulus vs Number of cycles

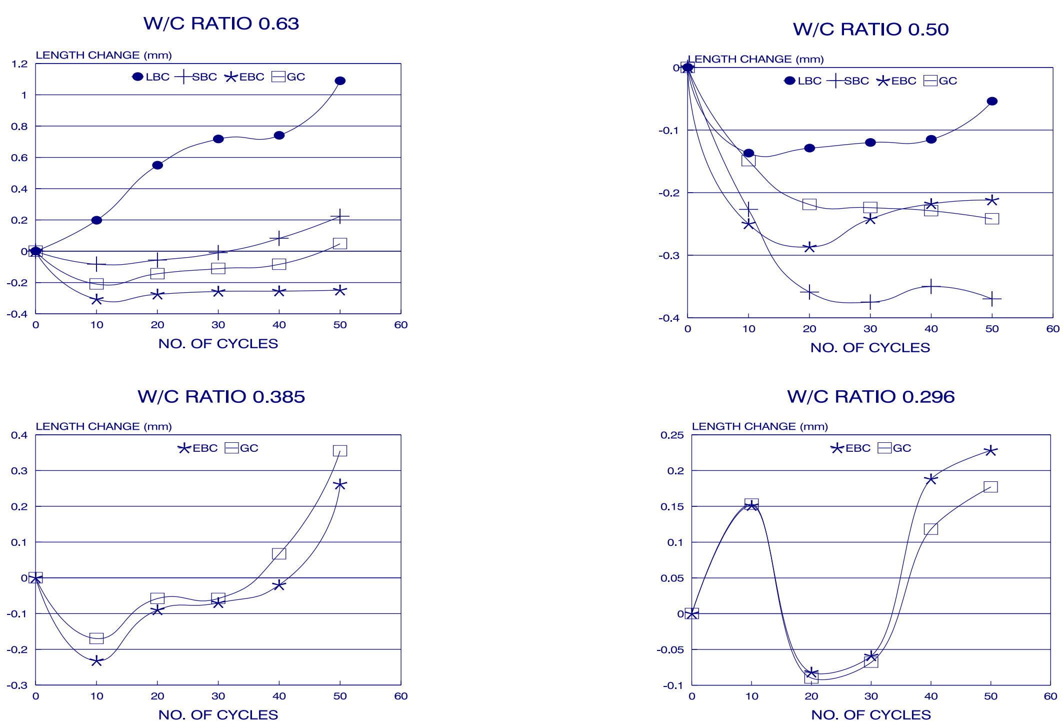

Figure 2. Variation in length vs Number of cycles

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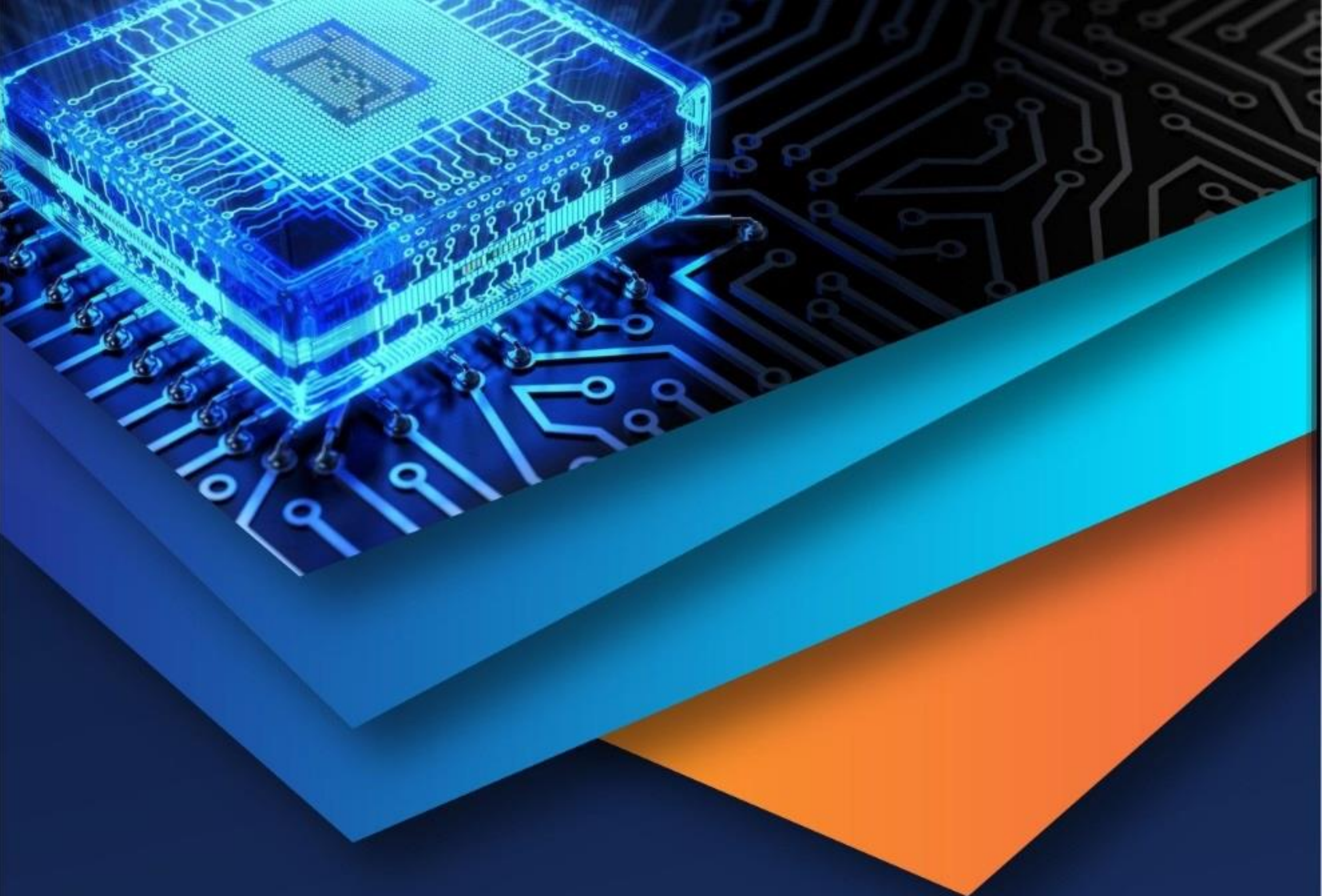

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