Flexural Strength Deterioration of Steel Fiber Reinforced Concrete Due to High Temperature

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ABSTRACT

There are important cases in which concrete is exposed to high temperatures such as fire, chimmeys and refractory structures, etc. expoing concrete to high temperature causes strenghth deterioration, increase in drying shrinkages ,and the reduction in bond strength with reinforcement .

This investigation is carried out to study the effect of steel fiber addition on flexural strength deterioration of concrete exposed to high temperatures in the range of 20° to 800° C . The following variables are taken in to account : type of mix , fiber content and aspect ratio , heating duration and type of cooling . Test results have shown that the inclusion of steel fibers in concrete reduces the amount of strength loss due to heating , the degree of strength deterioration depends on the fiber content and high temperatures, and the bulk flexural strength lose occurs within two hours of heat exposure.

INTRODUCTION

Concrete is the first major synthetic building material which has led to considerable economy in building construction. However ,the material has certain limitations.The main structural limitations are:the low ratio of tensile to compressive strength , the poor resistance to impact and spalling and erratic level of durability.These limitations form the major reasons for the growing interest in the performance of fibers in cement based materials. Steel fiber reinforced concrete is being increasingly used in many construction especially for the purposes where the concrete is exposed to severe service conditions which include exposure to high temperature , such as lining of refractory structures . Exposing concrete to high temperatures causes strength deterioration , increase in drying shrinkage and risk of reinforcement corrosion .

Investigation on the effect of steel fibers on the properties of concrete at elevated temperature are recent and few in number . Purkiss(1) investigation on SFRC at high temperatures (300° to 800° C) showed that below 600° C SFRC performance was better than plain concrete and the volume fraction and type of the fiber seemed only to have a secondary effect . Fayiad and Al-Ausi(2) studied also the effect of method of re-coiling on the compressive strength of plain and SFRC . Their tests showed that re-coiling the SFRC in air causes an improvement in strength, however for all the mixes re-coiling in water caused further reduction in strength . Austin and Robins (3) have carried out an investigation to determine toughness index as a measure of refractory performance of steel fiber refractory concrete . To simulate service condition the test specimens were conditioned by cyclic heating . The results showed that toughness index increased with increasing the percent content of fiber , and the cyclic heating reduced the flexural strength . Very high temperature effect were studied by Lankard and Sheets (4) who had heated steel fiber refractory castables in the range of 537.8° C to 1649° C . They have concluded that significant improvements have been achieved in strength and thermal shock resistance . However , shrovanck and Herron (5) in their investigation on stainless steel fiber reinforced castables in the range 820-1100° C have found that the high temperature strength of refractory castables was not improved by the fiber addition , but the benefits of fibers were derived from the formation of ductile grid which held the weakened castable together , and reducing the tendency for spalling .

In this investigation tests are carried out on the effect of high temperatures on the flexural strength deterioration of steel fiber reinforced mortar and concrete . Different fiber volume fractions and fiber aspect ratios have been investigated as well as three different heating duration .

EXPERIMENTAL WORK

The experimental work consisted of tests on two different types of mixes. Mortar mix A , 1:3 cement:sand and concrete mix B , 1:3:2 cement:sand:gravel . For mix A three fiber volume percentages were used 0.0 , 0.5 and 1 . For mix B steel fiber percentages were 0.0,0.5, 0.75 and 1. For all the mixes tests were carried out at 20 , 200 , 400 , 600 and 800°C temperature levels .

The materials used for the mixes were : ordinary portland cement , river sand of zone 2 according to B.S. specifications and river gravel of maximum size 9.5 mm for mix B . Douform steel fibers of 0.30 mm diameter and 20 mm length , aspect ratio L/D = 66.66 were used . For mix B of 0.75% fiber two other fiber lengths were also tested . The fibers were 25 and 40 mm in length giving aspect ration of 83.33 and 133.33 respectively.

Water cement ratio for all the mixes was 0.6 and the materials were all proportioned by weight . Steel moulds were used to cast 100x100x355 mm concrete beams for two points loading flexural strength test according to ACI committee 544 Report (6) on fiber concrete . The specimens were de-moulded after 24 hours , placed in water tank for 28 day and then air-dried in the laboratory for 32 days before testing or exposure to temperature .

For all the temperature levels the rate of heating was nearly according to B.S.476 (7) . Once the required temperature level had been reached , the specimens were saturated thermally for two hours after which they were removed from the furnace and cooled in air to room temperature for a period of 20-24 hours before testing . In order to study the effect of heating duration few specimens of mix B with 0.75% fibers and aspect ratio 66.66 , were tested for heating duration of 1 , 2 and 3 hours . Also some mix B specimens were quenched in water after removal from the furnace in order to study the effect of rapid water cooling on its flexural strength deterioration .

Two electric muffle furnaces of maximum 1000°C were used for heating , both with automatic in-built thermostat and thermocouple enabling their temperatures to be recorded and controlled through out the heating process .

For each test at least three specimens were tested and the compressive strength of the mixes was determined from 100x100x100 mm cubes and the V.B times of the mixes were measured , these results are shown in Table 1 .

RESULTS AND DISCUSSION

Figures 1 , 2 and 3 show the results interm of modulus of rupture (MOR) vs. temperature level for A (1:3) , mix B (1:3:2) and mix B for different L/D respectively . Figures 4,5 and 6 show same results interm of percentage loss of MOR with temperature . The strength ratios (ratio of MOR of mixes containing steel fibers to MOR of plain mixes) at different temperature levels are shown in Table 2 .

The figures show that MOR of plain mixes deteriorated with temperature increase and the strength loss became sharp at and beyond 400°C . The trend of the strength variation of SFRC mixes with temperature is the same as for plain mixes but the degree of deterioration is less especially above 200°C . For the plain mixes the strength loss at 400°C is about 80% of the 20°C strength , while the % loss of strength for the fiberous mixes ranges between 24% to 61% depending on the fiber content. At 800° C the % loss of MOR for both plain mixes is about 100% however for the fiberous mixes the % losses vary from 64% to 90% .

The deterioration in MOR of concrete and mortar is attributed to the break-down of interfacial bond due to incompatible volume changes between cement paste and aggregate during heating and cooling , and it is also because of the formation of relatively weaker hydration products (dehydration of calcium silicate hydrate in cement paste) with poor binding properties . These reasons are affirmed by appearance of surface hair cracks noticed at temperatures above 200° C in the cement paste which increases in number , length and depth due to temperature rise .

Table 2 indicates that at all the temperatures fiberous mixes possess greater MOR as compared to the plain mixes and beyond 200° C the strength ratio rises with increasing the temperature level . This improvement in MOR is due to delaying and partial suppression of cracking caused by fiber addition . The cracks observed in SFR specimens were less and smaller than those which occurred in plain concrete specimens . The fibers also carry the tensile stresses formed while heating , cooling and testing .

Comparison of Figures 4 and 5 show that the % loss of strength of the mortar mix 1:3 is less than that of the concrete mix 1:3:2 indicating that mortar mixes perform better than concrete mixes when exposed to high temperatures , this may be due to the absence of the gravel . The presence of gravel helps in the production of high tensile stresses due to the incompatible movements of cement paste and aggregate at elevated temperatures . The absence of coarse aggregate also allows a uniform and better fiber distribution and reduces the possibility of fiber balling which increases the fiber capacity for carrying the tensile stresses produced while heating , cooling and testing .

Figures 3 and 6 show the relationship of MOR and its % loss with temperature for SFRC of 0.75% fiber content of different aspect ratios 66.66 , 83.33 and 133.33 . From these Figures it is shown that the % losses at 400°C are about 44% , 27% and 25% for fiber aspect ratios 66.66 , 83.33 and 133.33 respectively . At 800°C the % losses are nearly the same (about 79%) . The increase in MOR with increasing the fiber aspect ratio from 0 to 83.33 is due to the increase in interfacial bond between the matrix and fiber due to the increase in fiber length. However , increasing aspect ratio from 83.33 to 133.33 had almost no effect on MOR of SFRC for all the temperatures ,this may be due to the non uniform fiber distribution and the effect of fiber balling because of the low workability of the mix as indicated by the high V.B time for this mix

The effect of heating duration on SFRC is shown in Figure 7. The Figure shows higher MOR for concrete heated for 3 hours than that heated for 2 hours duration which means that there is a recovery in MOR of SFRC 3 hours heating . Bhai (8) has also observed a recovery in compressive strength when the heating duration increased from 3 hours to 4 hours , this strength recovery may be due to the uniform heat distribution achieved at 3 hours and the maximum loss at 2 hours may be due to the bulk thermal gradients reached at this exposure time .

The results plotted in Figure 8 show the change of MOR of plain and SFRC of 0.75 % fiber with temperature for two methods of cooling ; air cooling and water cooling . The Figure shows that the specimen cooled in water exhibited more strength deterioration than the air cooled specimens for both the plain and SFRC mixes . This is because of the destructive thermal shock produced when quenching the hot specimens in water and the penetration of water in to the concrete pores and cracks.

finally it is worth noting that for all the specimens tested and at all the temperature levels the failure of the specimens occurred by fiber pull-out.

CONCLUSIONS

The following conclusions can be drawn from the tests carried out in this investigation .

1- The flexural strengths of all the mixes tested show continuous deterioration with increasing temperature , however the residual strength of the mortar is more than that of concrete for all the temperatures .

2- Inclusion of steel fibers greatly improves the flexural strength of concrete , this improvement increases at high temperatures .

3- Bulk flexural strength loss of SFRC occurs within two hours of heat duration .

4- Increasing fiber aspect ratio from 83.33 to 133.33 shows no significant effect on flexural strength of heated concrete .

REFERENCES

1- Purkiss , J.A. , 1984 , " Steel Fiber Reinforced Concrete at Elevated Temperatures " , *The International Journal of Cement Composites and Lightweight Concrete* , Vol.(6) , No. 3 , P.179-184 .

2- Faiyadh , F.I. and M.A. Al-Ausi , 1986 , " Effect of Elevated Temperature and Method of Re-cooling on the Compressive Strength of Plain and Fiber Reinforced Concrete " , *Third Rilem International Symposium* , UK. , P. 255-230 .

3- Austin , S.A. and P.J. Robins , 1986 , " Toughness Testing of Steel Fiber Refractory Concrete After Cyclic Heating " , *Third Rilem International Symposium* , UK. , P. 363-370 .

4- Lankard , D.R. and H.D. Sheets , 1971 , "Use of Steel Wire Fibers in Refractory Castables " , *Bulletin Am. Cer. Soc.* , Vol.(50) , No. 5 , P. 497-500 .

5- Strevanck,S.D. and R.H. Herran,1980," High Temperature Mechanical Properties of Stainless Steel Fiber Reinforced Castables " , *Bulletin Am. Cer. Soc.* , Vol.(59) , No. 7 , P.742-745 .

6- ACI Committee 544 , 1984 , " Measurements of Properties of Fiber Reinforced Concrete " , *International Symposium on FRC Sp-81* , Michigan , P. 433-440 .

7- British Standards Institution , 1972 , " Fire Tests on Building Materials and Structures " , *BS 476* , Part 8 London .

8- Mohamed Bhai , G.T.G. , 1986 , " Effect of Exposure Time and Rates of Heating and Cooling on Residual Strength of Heated concrete " , *Magazine of Concrete Research* , Vol.(38) , No. 136 , P. 151-168 .

Table (1) : Test Details

mix proportion	fiber content %	aspect L / D	compressive strength N / mm^2	V.B. time seconds
1:3	0.00	-------	56.7	2.5
	0.50	66.66	62.9	6
	1.00	66.66	65.0	14
1:3:2	0.00	-----	45.3	3
	0.50	66.66	49.6	7
	0.75	66.66	52.1	13
	0.75	83.33	56.3	24
	0.75	133.33	53.9	46
	1.00	66.66	57.0	14

Table (2): Flexural Strength Ratio

mix proportion	fiber content %	strength ratio at temperature C°				
		20	200	400	600	800
1:3	0.50	1.2	1.2	3	5.3	17
	1.00	1.6	1.7	5.7	9.2	30
1:3:2	0.50	1.2	1.2	3.2	8	70
	0.75	1.2	1.3	4	9	100
	1.00	1.8	1.7	6.6	21	220

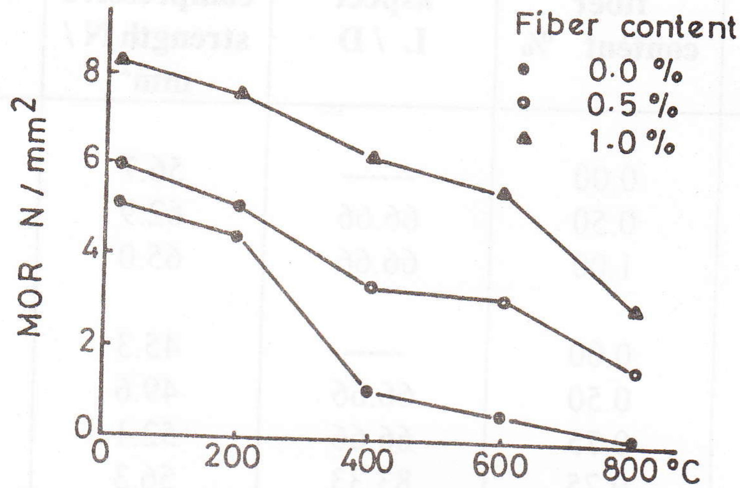

Fig. 1 MOR vs. Temp. (mix. 1:3)

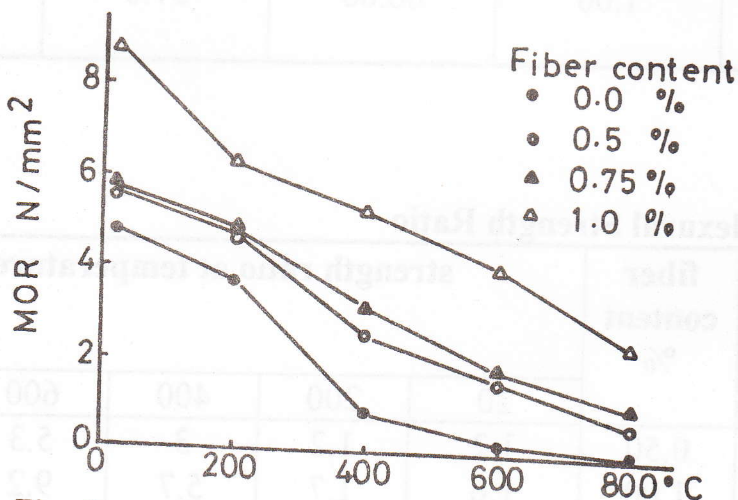

Fig. 2 MOR vs. Temp. (mix. 1:3:2)

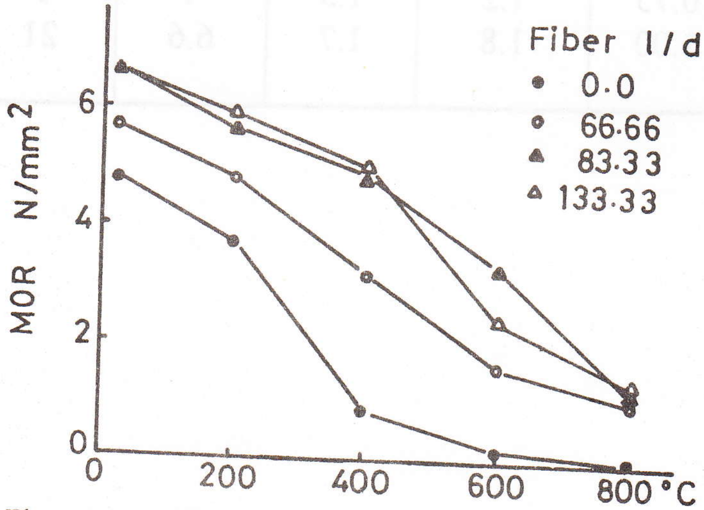

Fig. 3 MOR vs. Temp. for different l/d

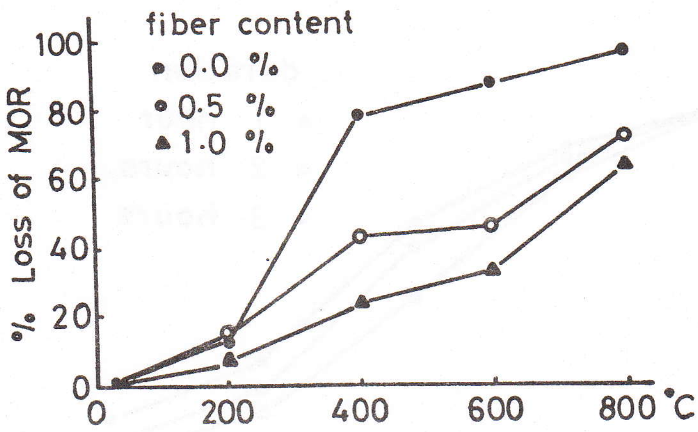

Fig. 4 % Loss of MOR vs. Temp. (mix 1:3)

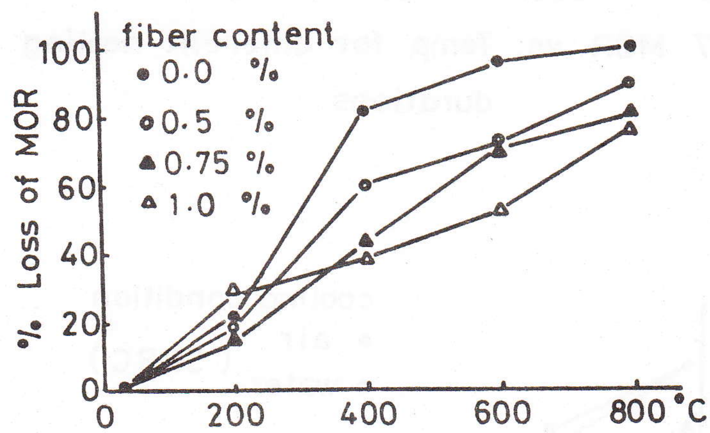

Fig. 5 % Loss of MOR vs. Temp. (mix 1:3:2)

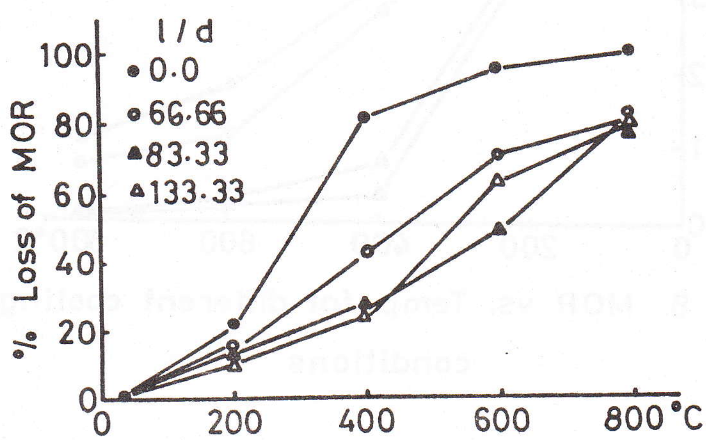

Fig. 6 % Loss of MOR vs. Temp. for different l / d

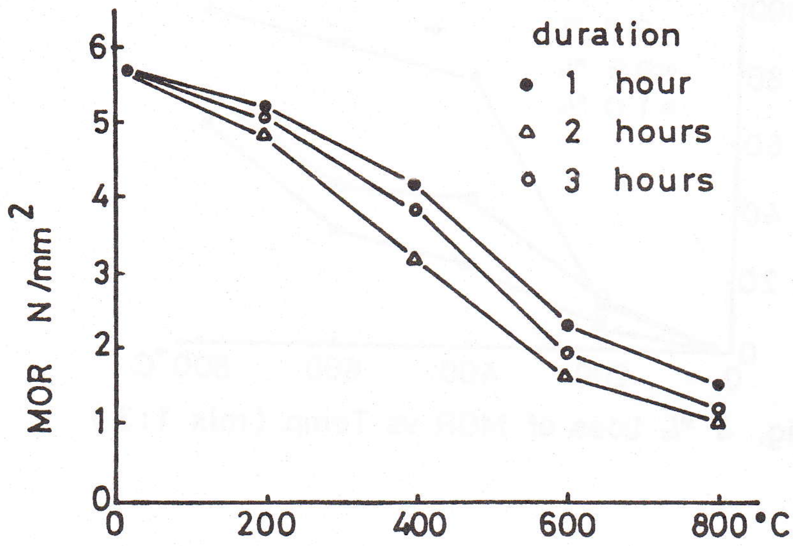

Fig. 7 MOR vs. Temp. for different heating durations

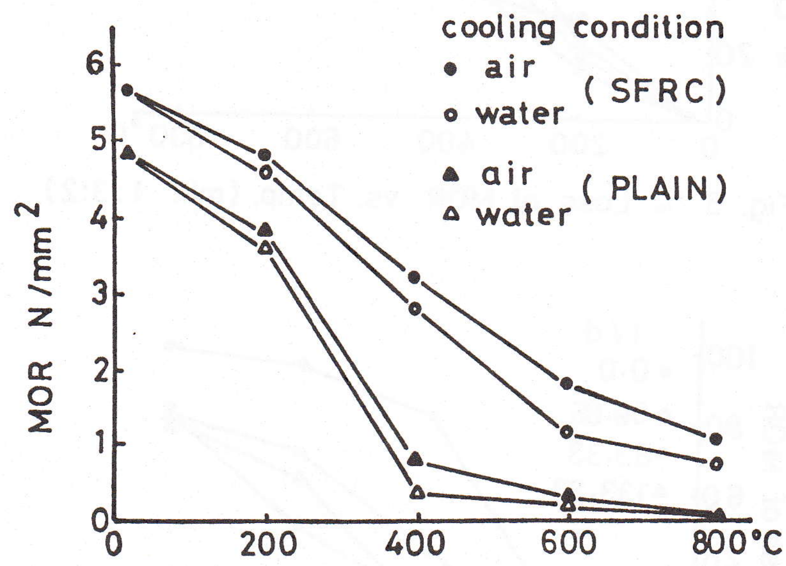

Fig. 8 MOR vs. Temp. for different cooling conditions

نقصان المقاومة الانثنائية للخرسانة المعززة بألالياف الفولاذية نتيجة درجات الحرارة العالية

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الخلاصة

أجريت هذه الدراسة لبيان تأثير اضافة الآلياف الفولاذية الى الخرسانة على مقاومتها الانثنائية عند تعرضها الى درجات الحرارة العالية في حدود ٢٠ الى ٨٠٠ درجة مئوية . وقد تم أخذ المتغيرات التالية بنظر الاعتبار : نوعية المزيج ، كمية الالياف ونسبتها الباعية ، فترة التعرض للحرارة ونوع التبريد . وقد بينت النتائج بأن اضافة الالياف الفولاذية تقلل من الفقدان في المقاومة ، وتعتمد كمية الفقدان في المقاومة على كمية الالياف ونسبتها الباعية . وتكون نسبة التحسن جيدة عند الدرجات الحرارية العالية كما وأن معظم فقدان المقاومة تحصل خلال الساعتين الاولى من التعرض للحرارة العالية .

كەم بونەوەی بەرگری خواربونەوەی کونکریتی بەهێزکراو بە وورده ئاسن بە هوی پاەی گەرمی زۆر بەرزەوە

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کورتە

ئەم لێکولینەوەیە کرا بو دوزینەوەی کاریگەریی بەهێزکردنی کونکریت بە وورده ئاسن لە بارەی بەرگری خواربونەوە کاتی دەخریتە ژێر پلەی گەرمی زۆر بەرزەوە لە ٢٠ بو ٨٠٠ پلەی سەدی . ئەم فاکترانە رەچاو کران : جوری تێکەڵ ، بڕی وورده ئاسنەکەو درێژی وئەستوری ، ماوەی گەرم کردن وجوری سارکردنەوەی .

ئەنجامەکان پیشانیان دا کە بەهێزکردنی کونکریت بە وورده ئاسن لە بەرگری لە دەست چوو کەم دەکات . بڕی ئەو کەم بوونەوەیە پەیوەستە بە بڕی وورده ئاسنەکەو درێژیەکەیەوە . وە بەرزبوونەوەی بەرگری لە پلەی گەرمی بەرزدا زۆرترە وە هەروەها بەشی زۆری بەرگری لە دەست چوون لە دووکات ژمێری سەرەتادا روودەدات .