THE EFFECTS OF CRACKING ON THE MODULUS OF RUPTURE OF CONCRETE

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Abstract

This paper presents the effects of cracking on the modulus of rupture of concrete. The cracks and the modulus of rupture are calculated by understanding the behaviour of concrete, when reversal zones are achieved. The compressive zone is analysed as the tensile zone and the tensile zone is analysed as the compressive zone. This phenomenon is tested by applying load on one side of a concrete beam until appropriate cracks are seen and then the beam is flipped onto its other side with no cracks, and load is rested and applied again until complete failure. The final result is then presented and compared with modulus of rupture of un-cracked beams and the conclusion is based on the result.

Keywords: Cracks, Modulus of Rupture, Reversal Zone, Compressive Strength

1. Introduction

Modulus of rupture can be defined only for brittle materials where resistance to deformation is studied. In this case the proportional limit of the material is exceeded and the stress obtained is called as the modulus of rupture. (Pytel, 1987)

Modulus of Rupture is also known as Flexural Strength, Bending Strength and Fractural Strength. The Modulus of Rupture can be calculated by conducting either one of the three types of tests listed below:

- Centre-Point Loading Test (ASTM C293)
- Third-Point Loading Test (ASTM C78)
- Compressive Test (ASTM C39)

The Centre point loading flexural test is carried out by applying load on the centre of the beam, therefore the maximum stresses are only present at the centre of the beam. In the centre-point loading flexural test, the area of failure not only contains moment induced stresses but also shear stress and unknown areas of stress concentration. The modulus of rupture of Centre point loading test is approximately greater than 15% of the modulus of rupture calculated in Third point loading test (ACPA, 2001).

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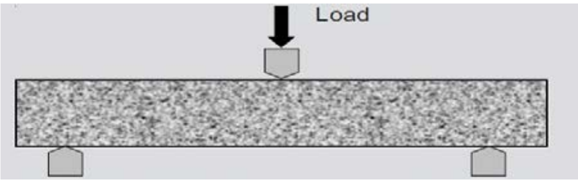
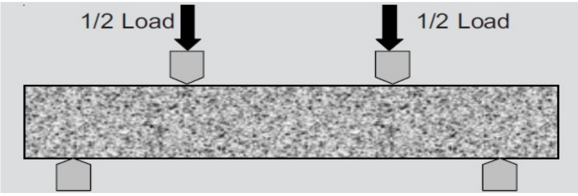
Figure 1: Center Point Loading



Source: ASTM C293,2010

The Third point loading flexural test is experimented by applying half loads at 1/3rd portion of the beam and in the middle third of the span. The sample is subjected to pure moment with zero shears. The modulus of rupture determined from third point loading system is used in design, whereas the modulus of rupture determined from centre point loading system is used in quality control if the relationship to third point system is known.

Figure 2: Third Point Loading



Source: ASTM C78, 2015

In the compressive test a compressive axial force is applied to a cylinder specimen until failure occurs. The Modulus of rupture is then calculated by using an empirical formula.

The modulus of rupture which is concerned with the tensile strength of concrete beams is dependent on the size of the beam. Whereas the relation is statistical and is caused by the intrinsic material but it ignores the stress distribution caused by cracks prior to maximum loads.

2. SAMPLING

The contents of concrete were mixed by using volumetric method. Volumetric method was used so that the beams are more close to the practical applications of site. Three ratios were used for sampling.

- 1:1:2
- 1:1.5:3
- 1:2:4

The samples were cured for 28 days at room temprature and then taken for testing. The Aggregate size was taken in accordance to ASTM C33 (which should be passing through the sieves ¾ “to 4”). The water to cement ratio was taken as 0.5 and samples were reinforced.

The samples were further classified into beams and cylinder samples. Each ratio had 3 cylinder samples and 6 beam samples. The beam samples were casted for the modulus of rupture testing, whereas the cylinder samples were casted for the compressive strength of concrete, from which then the modulus of rupture was determined.

3. REINFORCEMENT OF SAMPLES

The beam samples were reinforced in accordance to the equation of balanced reinforcement given in Chaper 8 (8.4.3) of ACI 318:

$$\rho_b = \frac{0.85 f_{c'} \beta}{f_y} \left(\frac{87{,}000}{f_y + 87{,}000}\right)$$

Here:

ρ_b = Balanced Reinforcement Ratio,

$f_{c'}$ = Compressive strength of Concrete at 28 days,

β = Coefficient of Compression,

f_y = yielding strength of steel.

It was taken into account that the sample reinforcement was less than the calculated ρ_b value in the equation, as to achieve under reinforcement.

4. RESULTS

Calculations were done and following results were obtained which were then taken into consideration, and analyzed to produce a conclusion.

The Compression test (ASTM C39) gave the following results

Table 1: Results of Compressive tests

S.No	Sample Name	Ratio	Maximum Force Required (F) / lbf	Radius of Cylinder (r) / in	Area Of Cylinder (A) / in^2 $A = \pi r^2$	Compressive Strength/ psi $f_c = \frac{F}{A}$
1	112. 1	1:1:2	68164.1	3	28.27	2410.81
2	112. 2	1:1:2	82686.9	3	28.27	2924.45
3	112. 3	1:1:2	81475.2	3	28.27	2881.60
4	124. 1	1:2:4	73976.7	3	28.27	2616.39
5	124. 2	1:2:4	46348.3	3	28.27	1639.24
6	124. 3	1:2:4	64567.7	3	28.27	2283.61
7	1153. 1	1:1.5:3	85686.3	3	28.27	3030.53
8	1153. 2	1:1.5:3	59734.9	3	28.27	2112.69
9	1153. 3	1:1.5:3	61659.6	3	28.27	2180.76

Source:Primary Data

4.1 RESULTS OF FLEXURAL TESTS

As specified earlier 18 samples were tested for flexure out of which 9 beam samples were cracked and 9 beam samples were un-cracked. The un-cracked samples were taken into account for comparison, and later taken into consideration for a conclusion, so that effects of the cracks behaviour on the overall strength would be taken into account.

The results of the samples were as follows:

a) Without Cracks

Table 2: Flexural Tests Without Cracks

Sample Name	Ratio	Force(P) / lbf	MOR/ psi	Average MOR/ psi
112. 2	1:1:2	18200.00	2148.62	1963.55
112. 3	1:1:2	16788.20	1981.93	
112. 4	1:1:2	14909.10	1760.11	
124. 1	1:2:4	11353.10	1340.90	1020.95
124. 2	1:2:4	8081.49	954.06	
124. 3	1:2:4	6504.53	767.89	
1153. 1	1:1.5:3	16275.40	1921.5	1809.33
1153. 2	1:1.5:3	14870.50	1755.5	
1153. 3	1:1.5:3	14831.90	1751.0	

Source: Primary Data

b) With Cracks

Table 3: Flexural Tests with Cracks

Sample Name	Ratio	Force Required (P) / lbf	Crack Width/ in	Crack length/ in	MOR/ psi	Avg. MOR /psi
112. 1	1:1:2	14371.80	0.060	4.90	1696.67	2012.1
112. 5	1:1:2	15829.30	0.087	5.36	1868.74	
112. 6	1:1:2	20929.00	0.040	5.03	2470.78	
124. 4	1:2:4	6076.05	0.165	4.25	717.31	956.55
124. 5	1:2:4	6501.02	0.11	4.26	767.48	
124. 6	1:2:4	11730.60	0.047	4.03	1384.87	
1153. 4	1:1.5:3	18997.30	0.083	4.02	2242.74	1848.8
1153. 5	1:1.5:3	14673.80	0.070	4.26	1732.33	
1153. 6	1:1.5:3	13311.10	0.357	4.572	1571.45	

Source: Primary Data

*The crack width and crack length was calculated via photogrammetry.

5. CORELATIONS

From the results in table above correlation of samples were as follows.

Table 4: Corelations

Sample ratio	Average MOR of un-cracked Samples/ psi	Average MOR of cracked Samples/ psi	Difference/ psi	Percentage
1:1:2	1963.55	2012.10	-48.55	-2.47
1:2:4	1020.95	956.55	64.40	6.31
1:1.5:3	1809.33	1848.80	-39.47	-2.18

From table 4, it is evident that there is a slight or no difference between the MORs of the cracked and un-cracked samples. The percentage difference between the samples is less than 10% and the difference is less than 65 psi.

6. CONCLUSION

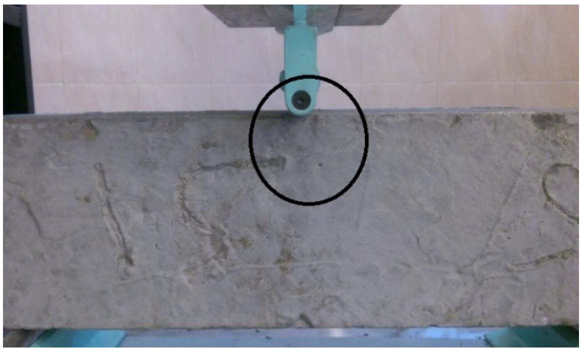
a) Difference between the MOR of the cracked and un-cracked samples is not that much deviated.

From table 2 and table 3, the samples 112.2 and 112.6 have a little difference between MOR whereas sample 112.1 and sample 112.3 are in the same range. From table 2 and table 3, the sample 124.1 and sample 124.6 have a slight difference; sample 124.3 and sample 124.5 have a little difference in the MOR, a difference of 0.41 pounds.

For the cracked samples, when the sample is flipped and test is restarted and force is applied again, the cracks which were result from the earlier force vanished. (see figure 3 and figure 4).

Figure 3: Cracks Diminishing

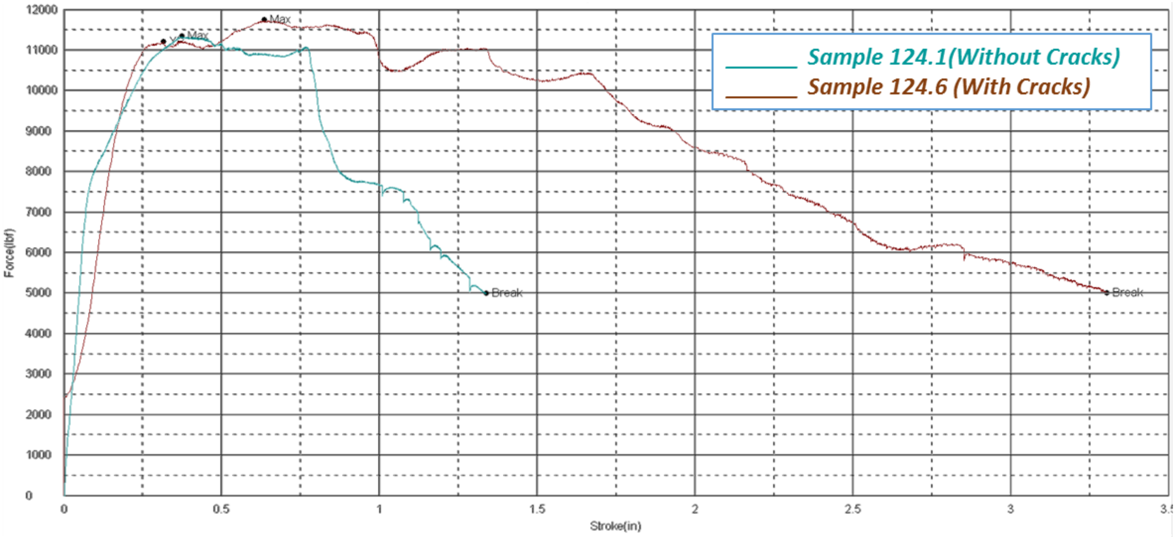
Figure 4:Cracks Diminishing



This behaviour of cracks is due to the compression zone been closing down and the tensile zone been opening up.

b) Some of the cracked and un-cracked samples have similar characteristics

Figure 5: Comparison of Cracked and Uncracked Charactersticks



Therefore the effect of cracking on the modulus of rupture of concrete, keeping in mind, the following results and discussions is very little or none. This is because of the cracks which develop in the tensile zone when reversed close up in the compression result in a compacted or free of cracking compressive zone.

The tensile zone in the reversed condition when becomes the compressive acts as in compression and the cracks disappear leaving the concerned beam behaviour as there was no force applied on it.

This research helps us understand the behaviour of concrete close to failure in under-reinforced beams where tension failure occurs first. It makes it clear that when an under-reinforced beam, in circumstances of close to failure if changed and reversed, where the tension becomes the compression and the compression becomes the tension, behaves as nothing has happened to it and failure can be avoided

The effects of cracking on the overall strength of the building when reversal zones are achieved, in this case, are very little. As the renewed zone of tension takes over the cracked and damaged zone. The damaged zones where cracks are seen are changed into compressive zones and in an under-reinforced beam tensile zones fail first, thus there is a slight effect of cracking in the case of reversal zones.

This all can be an effect of the stresses already present within the beam because for cracks some load is applied before flipping the beam. The stresses produced in the beam can cause a pre-stressing effect which might cause the cracked sample to break at the same reading as compared to that of the un-cracked sample.

7. RECOMMENDATIONS

The phenomenon of pre-stressing causing such behaviour of the sample should be investigated for further clarification of the results. The residual stresses in the concrete beam produce an extra force in the samples and cause the beam to break at the same point.

It is further recommended to test the same phenomenon by carrying out more tests.

This phenomenon should also be tested taking into account the micro cracking as in these tests the effect of micro cracking wasn't taken into consideration.

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