ASPS Conference Proceedings 1: 1323-1326 (2022)

Proceedings of

12th Structural Engineering Convention-An International Event (SEC 2022)

Available at https://asps-journals.com/index.php/acp

A comparison of stress-strain behaviour of conventional and high strength concrete

V. Bhonde [1], M. Fadadu [1], S. Patel [1], M. Mungule [2], K. K.R. Iyer [2, *]

[1] Department of Civil Engineering, Formerly B. Tech. student, Institute of Infrastructure Technology Research and Management, Ahmedabad, 380026, Gujarat, India

[2] Department of Civil Engineering, Assistant Professor, Institute of Infrastructure Technology Research and Management, Ahmedabad, 380026, Gujarat, India

Paper ID - 110189

Abstract

Strength performance of concrete is characterized by its compressive strength, elastic modulus, stiffness and energy absorption capacity. Stress strain behaviour of concrete encompasses information on all these parameters, and is thus one of the most vital data to assess its overall performance. The present study utilizes the stress strain response, as a tool, to compare the relative variation in performance of conventional and high strength concrete. Two set of mix compositions (viz., M40 and M80 grade concrete) have been designed. The designed compositions are checked for their target strength by performing load controlled tests on 28 day cured cube specimens. M40 grade concrete comprises of cement and water as binding material, and fine and coarse aggregates as filler. High strength concrete (M80 grade) is designed with cement, mineral admixture and water as binding material; while the fine and coarse aggregates contribute to the filler material. For high strength concrete, super plasticizer has been added in required proportion to ensure adequate workability. Displacement control tests, with controlled strain rate, have been performed on 28 day cured cube specimens. Variability in pre-peak and post-peak stress strain response is analysed for both conventional and high strength concrete. An average of response over atleast four samples is computed for both the M40 and M80 grade concrete. In present study, the characteristic response is normalized with respect to peak strength to obtain a common reference basis and compared. The comparison is summarized in terms of change in pre-peak response and post-peak ductility. The observed results enable quantification of relative change in performance for M40 and M80 grade of concrete. The results are significant for benchmarking performance of high strength concrete structures with those of conventional concrete structures.

Keywords: Conventional Concrete, High Strength Concrete, Stress-strain Behaviour, Ductility

1. Introduction

Concrete is a composite material that includes coarse aggregate, fine aggregate (sand), cementitious material, water and other admixtures as required to alter its properties. Portland cement is the common cementitious material in concrete along with supplements such as fly ash, silica fume, ground granulated blast furnace slag (GGBFS), etc. [1]. The use of supplementary cementitious materials helps improve strength and durability properties of concrete [2, 3]. It also contributes to reduction in consumption of cement thus enhancing sustainability of civil engineering infrastructures [4]. As concrete is brittle material and weak in tension, reinforcement is provided to control its cracking and enhance its ability to take tensile and flexural forces [5, 6]. In recent years, high strength concrete has become quite popular owing to requirements of higher strength for various structures such as high rise buildings, bridges and large span structures. High strength concrete is also necessary in aggressive environment to account for the reduction in strength due to deterioration of concrete, and hence enhance its life [7-9]. High strength concrete is also desired in pre-stressed concrete [10]. For ensuring the better performance of the structures which utilize high strength concrete, its various properties such as compressive strength, elastic properties, stress-strain response during loading and failure pattern needs to be understood in comparison to the conventional concrete. Keeping this in view, the present study focusses on comparison of the stress-strain behaviour of conventional concrete (M40) with high strength concrete (M80). Both load control and displacement control tests have been conducted on M40 and M80 concrete and the observations from the experimental study have been presented.

2. Methodology

In the present study, M40 and M80 concrete have been studied by load control tests to obtain their characteristic compressive strength. Further, the stress strain response has also been studied by displacement control tests for unreinforced and fibre-reinforced M40 concrete, as well as unreinforced M80 concrete. Four specimens each of M40 and M80 grade concrete have been subjected to load control and displacement control tests. For preparing M40 concrete, 0.5% plasticizer (Ether-based polycarboxylate) has been utilized to improve the workability with water to cement

*Corresponding author. Tel: +91-79-67775413; E-mail address: kannaniyer@iitram.ac.in

Published online: December 19, 2022
doi:10.38208/acp.v1.658

ratio as 0.4. For M80 concrete, 2% plasticizer has been utilized along with 15% metakaolin based on mix design at water to cement ratio of 0.26. For M80 concrete, the aggregates in range of 10-20 mm size is restricted to 40% while, remaining aggregates are smaller than 10mm size. Mix-design of concrete has been done as per IS10262 and IS456 for M40 and ACI211.4R-08, IS10262 and IS456 for M80 [11-13]. For the displacement controlled tests, the rate of displacement has been considered as 2.5 µm/s [14].

3. Discussion of Results

Based on the load control tests conducted on four specimens each of M40 and M80 concrete, the average compressive strength and standard deviation has been computed and presented in Table 1. It can be observed that for both M40 and M80 concrete the strength achieved were higher than the target strength. Further, the standard deviation for M80 concrete is higher than M40, indicating relatively higher variation in peak strength for M80 concrete.

In order to understand the stress-strain response, displacement control tests were performed on four specimens each for both M40 and M80 concrete. The average stress-strain response has been plotted in Figure 1. It can be observed that the initial stress-strain response for both M40 and M80 concrete are comparable, however M80 concrete exhibits stiffer stress-strain response subsequently. The strain corresponding to peak strength for both M40 (15.50×10^{-4}) and M80 concrete (10.87×10^{-4}) indicates that M40 attains peak strength at a larger strain as compared to M80 concrete. Post-peak response of M40 concrete indicates gradual reduction in strength with increase in strain, however for M80 concrete; the reduction in post-peak strength is sudden. This indicates that M80 concrete exhibits more brittle response as compared to M40. During the testing it was observed that M40 concrete exhibited cracks during pre-peak region and the cracks propagated gradually till peak strength and then progressively increased upto failure. In contrast, M80 concrete did not exhibit any visible indication of cracks in pre-peak region and post-peak response indicated sudden failure. The post-peak ductility of M40 concrete is evidently higher than that for M80.

The average peak strength obtained from stress-strain response for M40 and M80 concrete are 46.76 MPa and 86.0 MPa, respectively. The standard deviation from displacement control tests for the four specimens of M40 and M80 concrete were noted as 2.97 MPa (6.35 % of peak strength) and 5.06 MPa (6.50% of peak strength) respectively. The lower standard deviation of M40 concrete also suggests comparatively homogeneous response of M40 concrete among the different specimens as compared to M80.

Table 1. Average compressive strength results for M40 and M80 concrete

Details of concrete	Average compressive strength (MPa)	Standard deviation (MPa)
M40	49.2	1.99
M80	86.3	3.74

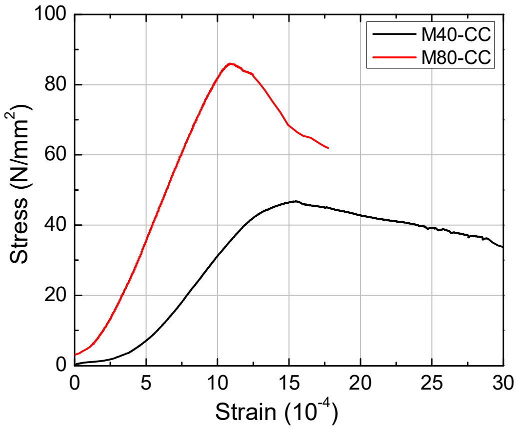

Fig. 1 Comparision of average stress-strain response for M40 and M80 concrete

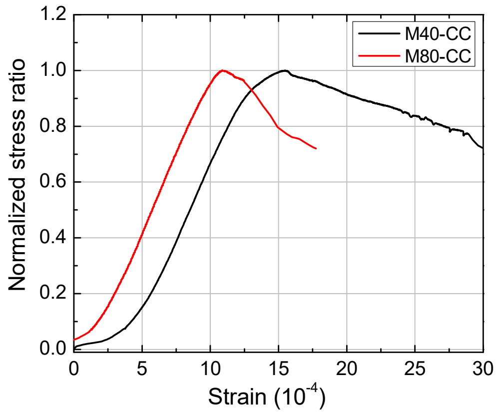

Fig. 2 Comparision of normalized average stress-strain response for unreinforced M40 and M80 concrete

Further, in order the compare the evolution of stress-strain curve during loading, the variation of normalized stress ratio with strain has been plotted for both M40 and M80 concrete. The normalized stress ratio is defined as the ratio of stress to peak stress, and it indicates the comparative response of the material at similar stages of loading. It can be observed from the figure that initial response for M40 concrete is relatively softer as compared to M80 concrete. However, beyond the normalized stress ratio of about 0.1, the responses of both grades of concrete are comparable at different stages of loading in pre-peak region, with both M40 and M80 concrete exhibiting similar slope of stress-strain curve at different stages of loading in pre-peak region. However, post-peak response is quite different for M40 and M80 concrete. A gradual reduction in peak stress value is observed post-peak for M40, whereas M80 concrete exhibits sudden drop in peak stress indicating a sudden failure.

Further, in order to compare the failure angles of the two grades of concrete studied, Figures 3 and 4 shows typical failure of M40 and M80 specimen. It was noted that the average failure angle measured from horizontal for M40 concrete was 61.5°. For M80 concrete the failure angle was visibly lower than M40 concrete (due to variation in measured values, it was envisaged that more tests are required to conclude on the failure angle for M80 and the value has not been reported). The damage in the M80 concrete during failure was also observed to be more prominent than M40.

Fig. 3 Typical failure of M40 concrete without fibre reinforcement

Fig. 4 Typical failure of M80 concrete without fibre reinforcement

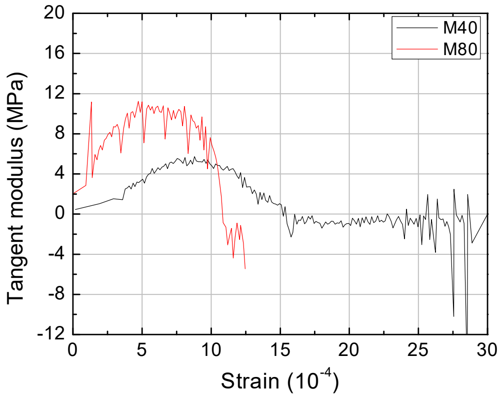

Fig. 5 Shows the tangent modulus for M40 and M80 concrete at different stages of loading

Further, to assess evolution of stress strain response, a comparative evolution of tangent modulus as function of strain is plotted for M40 and M80 grade concrete respectively. The observed response as in Figure.5 provides an insight into hardening or softening characteristics of the material. The hardening characteristics represent continued capacity of the material to take load whereas the softening behavior represents onset of micro-cracking. For M40 grade concrete, the tangent modulus increases gradually closer to the strain value representing approximately 60% of peak stress for the material. The softening curve thereafter is a result of micro-crack formation and coalescence that results into non-linearity in material behavior prior to attainment of peak load. The material continues to soften till peak load is achieved.

Softening representing post peak response is quite gradual and contributes to slow unloading of the material. In contrast for M80 grade concrete, higher value of tangent modulus with peak of hardening behavior representing approximately 85% of peak capacity indicate higher ability of the material to resist load without undergoing micro-cracking. However, the steep softening response indicate once the micro-cracking is initiated closer to peak stress, the cracks grow rapidly without much resistance indicating brittle behavior of the material. Based on the results, it can be argued that low strength concrete with higher damage susceptibility and damage tolerance has gradual softening response. On the other hand, high strength concrete has lower damage susceptibility accompanied with low damage tolerance indicate linear but brittle response of the material.

This study focuses on comparison of the compressive strength and associated stress-strain response for conventional and high strength concrete. It is opined that further studies are required on understanding the response of high strength concrete under tensile and flexural loading. It is also expected that the inclusion of fibres in concrete would enhance its response to loading including the ductility. Authors are pursuing separate studies in this direction with an overall objective to enhance the performance of high strength concrete under different loading conditions.

4. Conclusions

From the comparative study of stress-strain response for conventional concrete (M40) and high strength concrete (M80), the following conclusions have been obtained:

- The high strength concrete (M80) exhibits stiffer response during pre-peak region as compared to conventional concrete (M40). However, from the normalised stress ratio (ratio of stress to peak stress), it can be concluded that at similar stage of loading, both high strength and conventional concrete exhibit comparable stress-strain response in pre-peak region.
- The failure of high strength concrete is sudden, while that for conventional concrete is relatively progressive indicated by evolution and progression of the cracks until failure. The post-peak ductility of conventional concrete is observed to be higher than high strength concrete. This indicates that more care is required while utilizing high strength concrete in Civil Engineering structures, owing to its more brittle nature as compared to conventional concrete, to prevent catastrophic failure.
- The failure of high strength concrete is characterized by higher damage to the specimen as compared to conventional concrete.
- The results provide insight related to the performance of high strength concrete as compared to conventional concrete. The inferences from the study would help to benchmark the performance requirements for high strength concrete.

Acknowledgement

The authors extend their sincere thanks towards their University; Institute of Infrastructure Technology Research and Management (IITRAM), Ahmedabad, India for extending all the support and providing resources for performing the study.

Disclosures

Free Access to this article is sponsored by SARL ALPHA CRISTO INDUSTRIAL.

References

1. Malhotra, V. M., *Supplementary Cementing Materials*, CANMET Special Publication SP 86-6E, 1986, 428 pp.
2. Mehta PK. Advancements in concrete technology. Concrete International 1999; 96(4):69–76.
3. Poon C-S, Azhar S, Anson M, Wong Y-U. Comparison of the strength and durability performance of normal-and high-strength pozzolanic concretes at elevated temperatures. Cement and Concrete Research 2001;31(9):1291–300
4. Chen JJ, Kwan AKH. Adding limestone fine to reduce heat generation of curing concrete. Magazine of Concrete Research 2012; 64(12):1101–11.
5. Sivakumar A, ManuSanthanam, Mechanical properties of high strength concrete reinforced with metallic and non-metallic fibres, Cement and Concrete Composites Volume 29, Issue 8, 2007, pp. 603-608
6. P. Soroushian, A. Khan, J.W. Hsu, Mechanical properties of concrete materials reinforced with polypropylene or polyethylene fibers,

   ACI Materials Journal, 89 (1992), pp. 535-540
7. Bilodeau A, Kodur VR, Hoff GC. Optimization of the type and amount of polypropylene fibres for preventing the spalling of lightweight concrete subjected to hydrocarbon fire, Cement and Concrete Composites Journal 2004; 26(2): 163–75.
8. S. Kumar, Influence of water quality on the strength of plain and blended cement concretes in a marine environment,

   Cement and Concrete Research, 30 (3) (2003), pp. 345-350
9. A. Boddy, R.D. Hooton, K.A. Gruber, Long-term testing of the chloride-penetration resistance of concrete containing high-reactivity metakaolin, Cement and Concrete Research, 31 (5) (2001), pp. 759-765
10. Hueste M B, Chompreda P, Trejo D, Daren B. H. and Keating P B, Mechanical Properties of High-Strength Concrete for Prestressed Members, Structural Journal, 101(4), 2004,pp.457-465
11. IS 10262-2009, Concrete Mix Proportioning - Guidelines, Bureau of Indian Standards, New Delhi, India
12. IS 456-2000, Plain And Reinforced Concrete - Code Of Practice, Bureau of Indian Standards, New Delhi, India
13. ACI 211.4R-08 (2008), Guide for Selecting Proportions for High-Strength Concrete Using Portland cement and Other Cementitious Mater, American Concrete Institute, Farmington Hills, MI, USA.
14. Shah N., Mavani V, Kumar V, Mungule M, Iyer K.K.R, Impact assessment of plastic strips on compressive strength of concrete, Journal of Materials in Civil Engineering, ASCE, 2019, 31 (8), https://doi.org/10.1061/(ASCE)MT.1943-5533.0002784.