Assessment of Strength and Quality of Concrete Reinforced with Different Types of Steel Fibers

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***Abstract*— The reports of the past investigations have vividly expressed the significance of steel fibers and its contributions in enhancing the performance of concrete. The paper aims at investigating the most efficient and potential steel fiber among all four i.e. hooked, crimped, twisted and straight, that contributes in boosting the performance and quality of concrete after extensive examinations. Several concrete mixes were examined, incorporated with fly ash (FA) and metakaoline (MK) in various proportions.i.e.FA35%+MK4.5%,FA40%+MK9%,FA45%+MK13.5%,FA50%+MK18% and each composition is reinforced with four types of steel fibers in varying fractions of 0%, 0.5%, 1% and 1.5% to examine the potential of steel fibers in enhancing the properties of concrete for 28 days and 56 days curing period. After exclusive experimentations, It was finally confirmed that hooked steel fibers composite concrete mixes contributed the best performance among all other types of steel fibers whereas straight steel fibers showed a minimal performance compared to other steel fibers.**

Keywords*— *Compressive strength, flexural strength, porosity, ultrasonic pulse velocity tests, steel fibers, fly ash, metakaoline

I. INTRODUCTION

Concrete forms the most prominent building element in the field of construction industry that has been in use since decades. A lot of efforts have been made to discover the durable and serviceable concrete strong enough to sustain all adverse climatic conditions. Investigations are in progress to develop the sustainable and ecofriendly concrete by modifying with industrial waste materials such as fly ash, silica fume, GGBS etc. that plays a key role in boosting the strength properties of concrete.

Fly ash constitutes the major waste material that is obtained as a residue during the process of incomplete combustion of coal from thermal power stations. Past investigations proved that the replacement of cement with fly ash in concrete greatly improves the strength and durability of concrete.

Metakaoline, nowadays, forms the major puzzolonic material, that is obtained as a byproduct from the calcination process of clay mineral kaoline. It was been in use as a partial substitution of cement in concrete to examine the variations in the behavior of concrete and it was evident from the previous studies that it significantly influences the strength of concrete owing to its fineness property.

Steel fibers are utilized as an additive component in the mix to strengthen the compressive and flexural characteristics of concrete. There are various forms of steel fibers such as hooked steel fibers, crimped, straight, twisted, deformed, intended steel fibers categorized based on its configuration, that has been in use in concrete since decades that highly influenced the properties of concrete. Presently, four types of steel fibers i.e. hooked, crimped, straight and twisted steel fibers are included in every composition of concrete incorporated by fly ash and metakaoline to investigate the impact of steel fibers on the behaviour of concrete which is supported by several past researches discussed briefly.

II. LITERATURE REVIEW

Mahakavi P. et al. (2019), investigated on the effect of inclusion of hooked and crimped steel fibers on the fresh and hardened properties of self-compacting concrete. The results demonstrated that compressive, flexural and impact resistance improved significantly with the combined mix of steel fibers. Yoo D. et al. (2020), examined the tensile behavior of concrete by introducing corrosion straight steel fibers in various proportions in concrete mix. It was found that corrosion steel fibers enhanced tensile strength by 4 to 6 % without any deterioration of the bond resistance. Tai Y. et al.(2019), presented the computational model to observe the impact of twisted fiber on the pull out force and frictional behavior. The simulations revealed that maximum pull out force and energy dissipation capacity increased with the decrease in the pitch of the fiber twist. Yoo D., et at. (2019), experimented on the utilization of different types of steel fibres in ultra-high performance concrete to evaluate the potential of each fiber under extreme loading conditions. Results proved that straight or moderately deformed fibers perform well under extreme loading conditions than hooked and twisted steel fibers. Larsen I. L. et al. (2020), discussed upon the influence of steel fibers inclusion on compressive and tensile behaviour of ultra-high performance concrete and resulted that steel fibers exhibits major contributions in increase in tensile strength but improvement of compressive strength varies with the geometry of test specimens and other factors.

MATERIALS USED

1. Cement

Cement is one the major component in the manufacturing process of concrete. It has the property to stick to any other raw material added in the preparation process of concrete, especially when comes in contact with water and hence produces a good paste. Here, OPC 53 grade cement is used whose properties are shown below.

2. Fine Aggregate

Fine aggregate is first graded to decide the zone to which it belongs to. Generally, there are four categories of fine aggregate Zone-I, Zone-II, Zone-III & Zone-IV. In this work, sand of zone-II is chosen whose properties were given below. Generally, fine aggregate is passed through 4.75 mm sieve.

3. Coarse aggregate

Coarse aggregate is another fundamental raw material which gives strength, hardness and increases the volume of the concrete. Here, coarse aggregate of size 20 mm and angular crushed shape is chosen.

4. Fly ash

Fly ash is widely produced waste material across the globe and it constitutes the major industrial waste throughout, coming out from thermal power stations in the process of combustion of coal. Based on its chemical composition, it is categorized into two types class C and class F. Class C fly ash is highly reactive due to the presence of high content of calcium whereas Class F is slightly inert owing to its less calcium content.

Class F Fly Ash

5. Metakaoline

Metakaoline has gained tremendous significance in the construction industry due to pozzolanic characteristics. The calcination process of Kaolinite (China clay) results in the formation of highly pozzolanic reactive raw material Metakaoline. Metakaoline being finer in size and reactive in nature fills up the voids spaces in concrete that improves the mechanical properties of concrete to a huge extent.

Metakaoline

6. Steel Fibers

Four types of steel fibers are introduced in our present work which are hooked, crimped, straight and twisted steel fibers which are prepared from the mild steel drawn wires. All fibers are collected form Ajay Enterprises located in Rajgangpur, Odisha and are ensured to maintain the same aspect ratio of 50 with 30 mm length and 0.5 mm diameter, with the tensile strength of 1100 MPa and specific gravity 7.8.

7. Admixture

Superplasticizer "Conplast SP 430" is used for casting of concrete samples. It is made of Sulphonated Naphthalene polymer, specified as per IS: 9103-979 that achieves in reducing the water content by 20%.

8. Water

Normal tap water is utilized in the present work in the preparation of concrete specimens.

III. RESULTS & DISCUSSIONS

COMPRESSIVE STRENGTH RESULTS:

For 28 days curing period:

Tests were performed on all the concrete compositions reinforced with four types of steel fibers i.e. hooked, crimped, straight and twisted steel fibers to evaluate the compressive strength results after curing for 28 days. The results are presented in brief in the table below.

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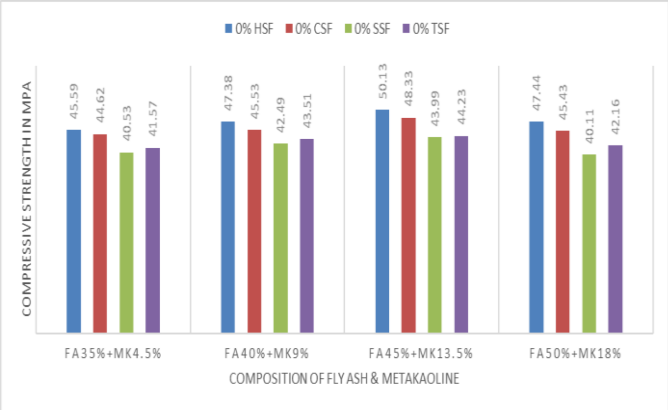

Fig 1: Compressive strength results for concrete mixes composed of various substitutions of FA+MK without any inclusion of steel fibers

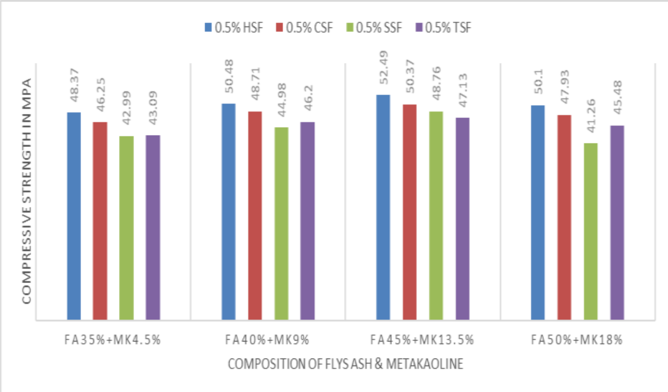

Fig 2: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 0.5% HSF, CSF, SSF & TSF

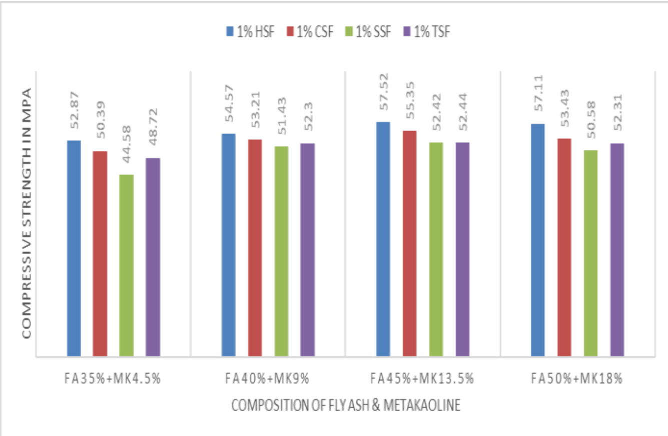

Fig 3: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1% HSF, CSF, SSF & TSF

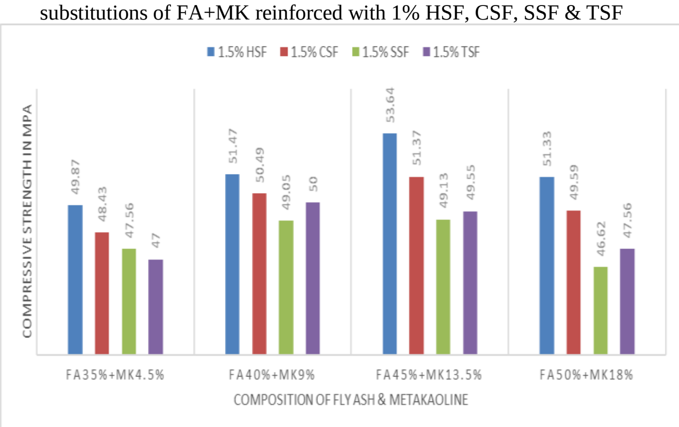

Fig 4: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1.5% HSF, CSF, SSF & TSF

For 56 days curing period:

Tests were performed on all the concrete compositions reinforced with four types of steel fibers i.e. hooked, crimped, straight and twisted steel fibers to evaluate the compressive strength results after curing for 56 days. The results are presented in brief in the table below.

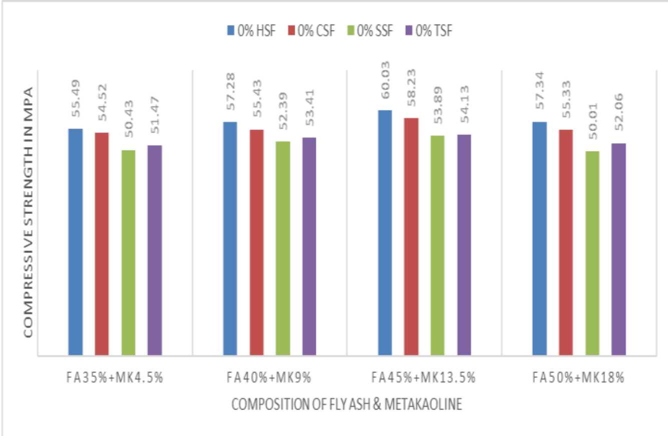

Fig 5: Compressive strength results for concrete mixes composed of various substitutions of FA+MK without any inclusion of steel fibers.

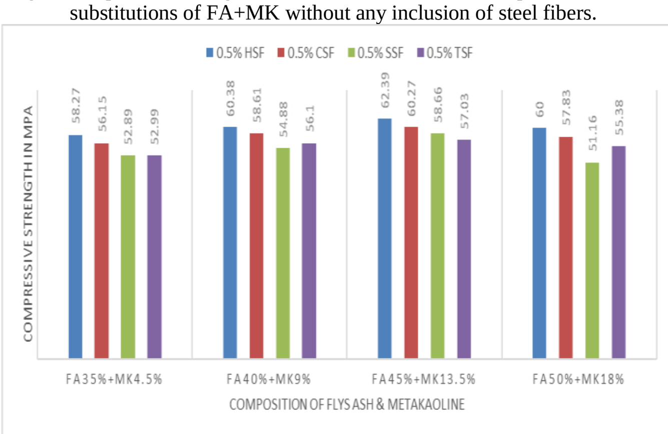

Fig 6: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 0.5% HSF, CSF, SSF & TSF

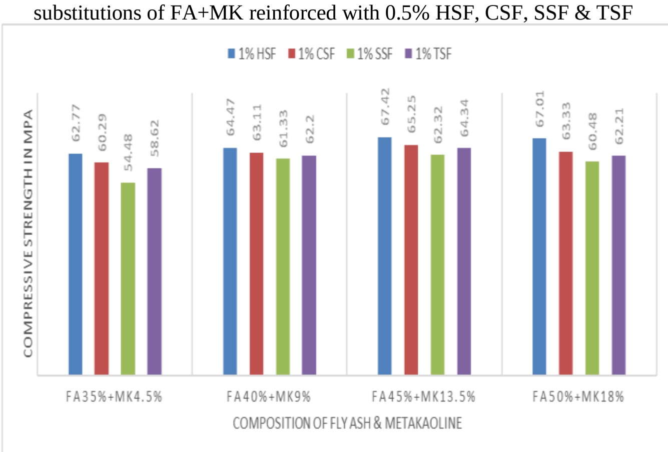

Fig 7: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1% HSF, CSF, SSF & TSF

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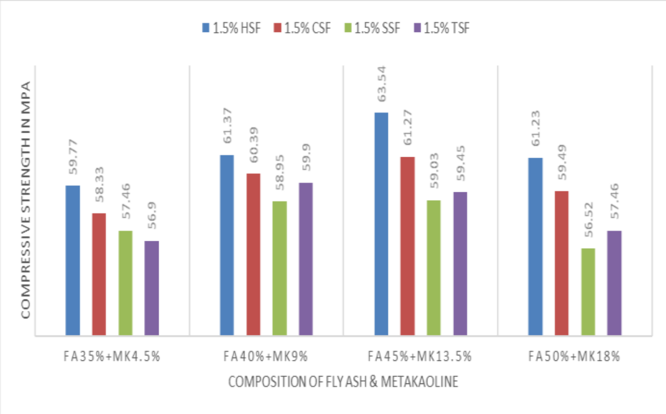

Fig 8: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1.5% HSF, CSF, SSF & TSF

FLEXURAL STRENGTH RESULTS:

For 28 days curing period:

Concrete prisms with different compositions of FA and MK reinforced with four types of steel fibers are tested for flexural strength as per IS 516-1959. The results obtained are shown clearly below for all compositions for 28 curing period

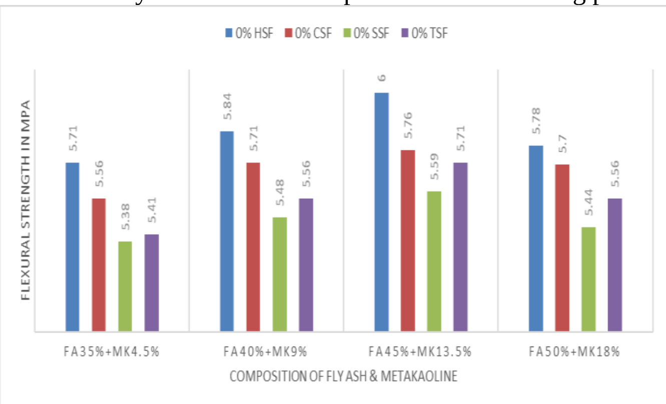

Fig 9: Flexural strength results for concrete mixes composed of various substitutions of FA+MK without any inclusion of steel fibers.

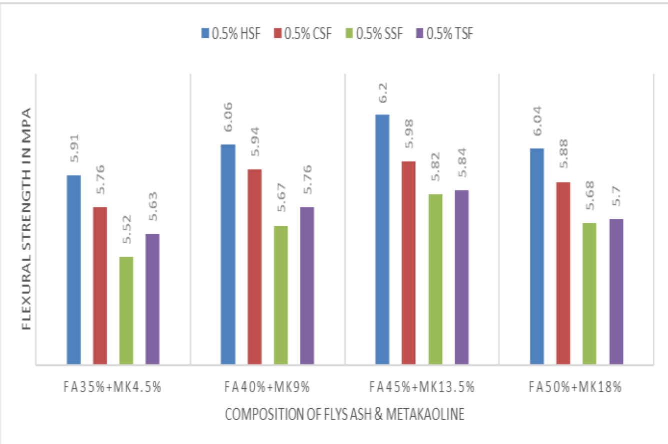

Fig 10: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 0.5% HSF, CSF, SSF & TSF

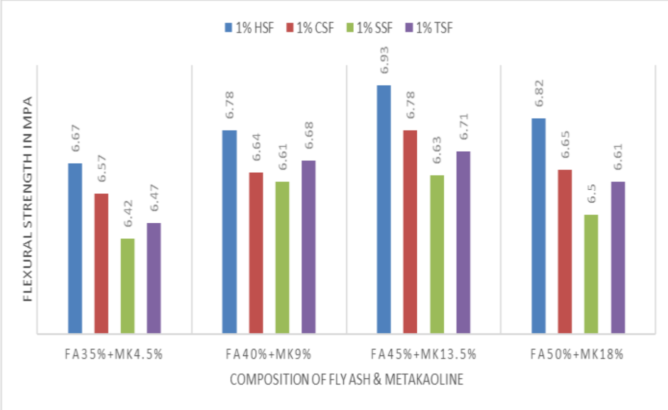

Fig 11: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1% HSF, CSF, SSF & TSF

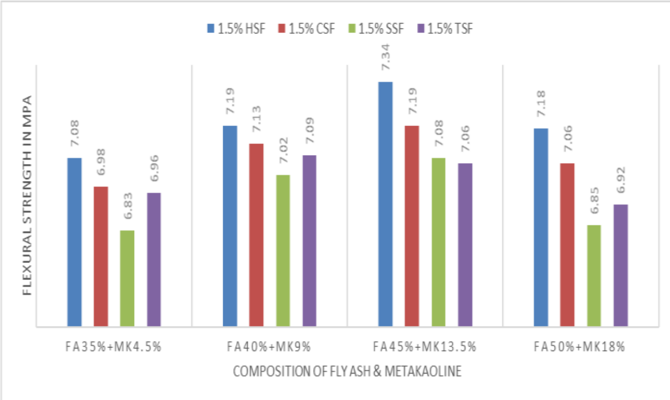

Fig 12: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1.5% HSF, CSF, SSF & TSF

For 56 days curing period:

Concrete prisms with different compositions of FA and MK reinforced with four types of steel fibers are tested for flexural strength as per IS 516-1959. The results obtained are shown clearly below for all compositions for 56 curing period.

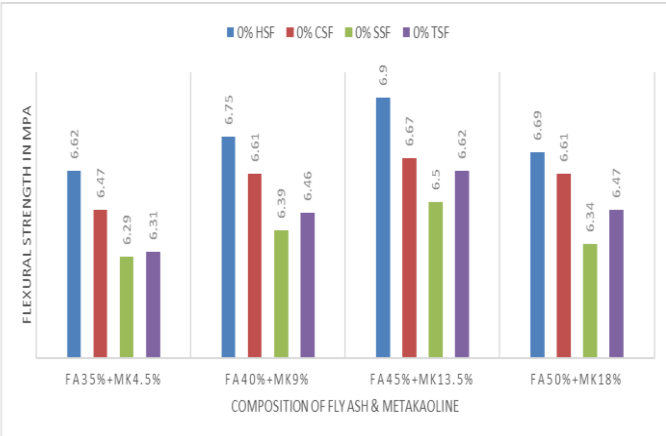

Fig 13: Flexural strength results for concrete mixes composed of various substitutions of FA+MK without any inclusion of steel fibers.

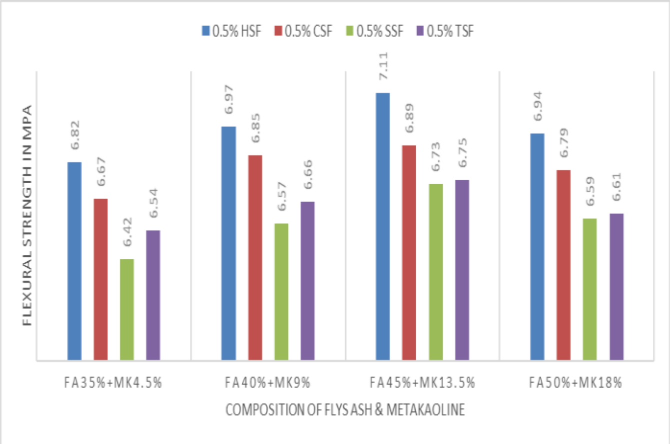

Fig 14: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 0.5% HSF, CSF, SSF & TSF

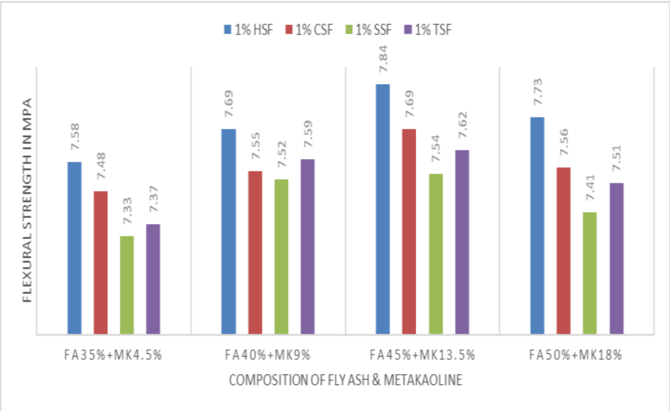

Fig 15: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1% HSF, CSF, SSF & TSF

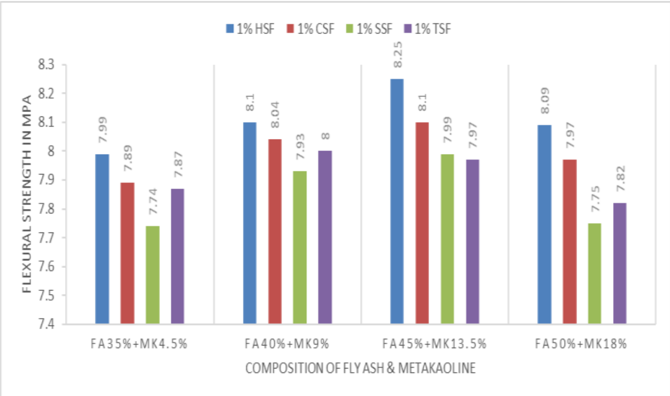

Fig 16: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1.5% HSF, CSF, SSF & TSF

POROSITY STUDIES:

Porosity is one such property that affects the durability properties of concrete such as water permeability, rapid chloride permeability, ingression of chlorine ions etc. Concrete specimens after curing for 28 days are subjected to105^{o}C heat curing for 2 days. Porosity is determined by evaluating the percentage loss of weight of the specimens after heat curing at a temperature of 105^{o}C. The porosity values for all mix compositions are shown clearly below

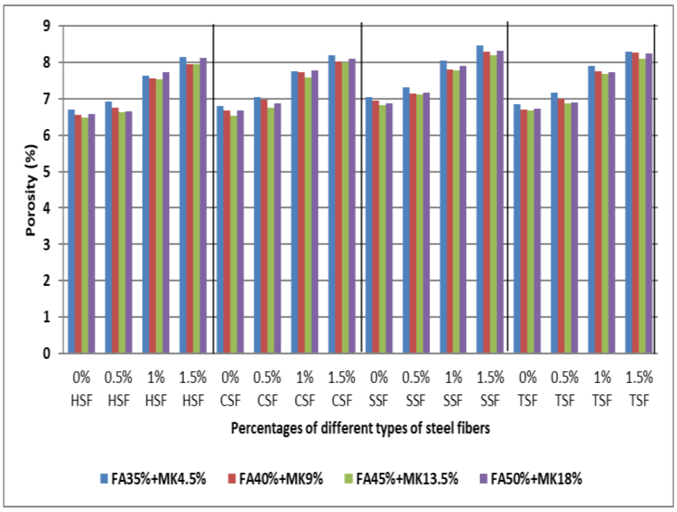

Fig 15: Cumulative graph showing the variations in porosity results for all concrete compositions included with different fractions of HSF, CSF, SSF & TSF

ULTRA SONIC PULSE VELOCITY RESULTS:

Ultrasonic pulse velocity tests are performed to detect the quality of the concrete by computing the time taken by ultrasonic pulse waves to pass through the concrete. As per ASTM C597, concrete specimens are categorized into excellent, good, doubtful and poor for UPV values of 4.5km/s and above, 3.5-4.5 km/s, 3.0-2.0 km/s and below 2.0 km/s respectively. UPV values for all the compositions are shown below.

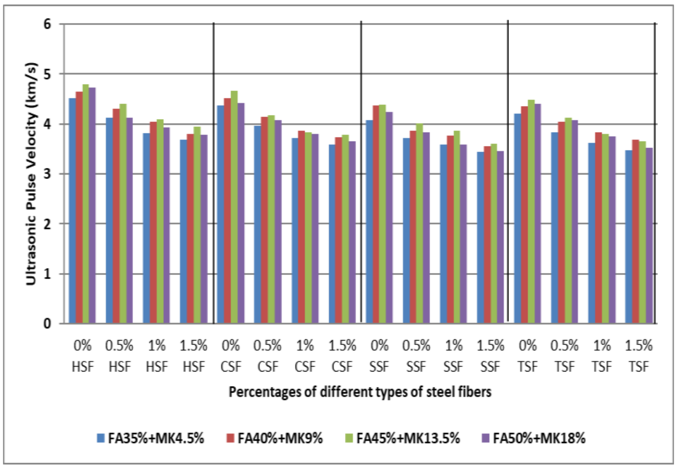

Fig 18: Cumulative graph showing the variations in UPV results for all concrete compositions included with different fractions of HSF, CSF, SSF & TSF

V. CONCLUSIONS

Following conclusions were extracted from the results and discussions obtained:

1. All compositions with hooked steel fibers showed extremely good compressive performance, followed by crimped, twisted and straight steel fibers respectively.
2. Highest compressive strength of 57.52 N/mm^2 is achieved by a composition of FA45%+MK13.5% with 1% hooked steel fibers among all other compositions for 28 days curing.
3. Highest compressive strength of 67.42 N/mm^2 is achieved by a composition of FA45%+MK13.5% with

1% hooked steel fibers among all other compositions for 56 days curing.

4. Excellent flexural performance was exhibited by all concrete mixes reinforced with hooked steel fibers, followed by crimped, twisted and straight steel fibers respectively.
5. A mix of FA45%+MK13.5% included with 1.5% hooked steel fibers yielded maximum flexural strength of 7.34 N/mm^2 and 7.99 N/mm^2 for 28 and 56 days curing respectively among all other mixes.
6. Concrete mixes hybridized by FA+MK, especially strengthened by hooked steel fibers exhibited least porosity values, followed by crimped, twisted and straight steel fibers respectively.
7. Concrete mix hybridized by FA45%+MK13.5% with 0% hooked steel fibers yielded the least porosity value of 6.48% among all mix proportions.
8. All concrete mixes incorporated with hooked steel fibers falls under the category of excellent quality determined as per ultrasonic pulse velocity test. This signifies that all these mixes are having fewer voids than other mixes.
9. A combined replacement level of FA45%+MK13.5% performed significantly better compared to other combinations of FA and MK.
10. Inclusion of hooked steel fibers in concrete compositions contributed excellent overall performance and proved to be the most efficient fiber among all fibers
11. Straight steel fibers exhibited least performance in terms of compressive, flexural, porosity and quality among all other fibers.

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