Investigation of Most Efficient and Potential Steel Fiber on Mechanical Behaviour of Concrete Blended with Fly Ash and Metakaoline

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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 steel fibers 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 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, steel fibers, fly ash (FA), metakaoline (MK), Hooked Steel Fibers (HSF), Crimped steel fibers (CSF), Twisted steel fibers (TSF), Straight steel fibers (SSF)**

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

The present work is drafted after referring the following previous researches:

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.
Hedjazi S., et al.(2020), conducted a comparative analysis on the impact of steel, glass and nylon fibers on the strength and UPV values of concrete. A new empirical approach was proposed to compute the compressive strength of concrete based on the fiber volume fraction.
Holschemacher K., et al. (2010), focused on the variations in the behavior of concrete modified with the utilization of three types of fibers such as straight, hooked and corrugated steel fibers in concrete mix. It was reported that presence of different types of fibers had a major impact on the flexural and tensile performance, fracture behavior and workability of concrete.
Celestine A. et al. (2020), aimed to study the behavior of M30 grade concrete prepared by replacing cement by 8% silica fume with inclusion of crimped steel fibers in varying fractions. Experiments were conducted to investigate the strength of concrete for 7 and 28 days curing.
Shen D., et al. (2019), attempted to research on the contributions of double end hooked steel fibers on the resistance of crack formation of concrete. It was examined that residual and free shrinkage stresses decreased significantly with the inclusion of hooked steel fibers.
Wang X., et al. (2019), performed the detailed experimentation to examine the efficiency of the numerous types of steel fibers and its aspect ratio on the strength of steel fiber reinforced cellular concrete. It was confirmed that higher compressive strength greatly depends upon higher steel fiber fractions and aspect ratio.
Liu F. et al. (2019), analyzed the importance of introduction of steel and PVA fibers in concrete to discuss the bending strength and crack resistance of concrete. Results indicated that steel fibers contributed in increasing the bending strength and PVA fibers exhibit better performance in crack resistance.
Han J. et al. (2019), presented the impact of steel fiber length and maximum coarse aggregate size on the strength properties of concrete. After experimentations, it was concluded that ratio of steel fiber to coarse aggregate maximum size had a great impact on fracture toughness, flexural performance and split tensile strength.
Siddique R. et al. (2016), aimed at analyzing the rheological, strength and permeation performance of concrete modified with fly ash and incorporated with steel fibers in varying fractions. It was noticed inclusion of steel fibers greatly enhanced the strength and offered higher resistance to chloride penetration but there was slight increase in porosity.
Guneyis E. et al. (2013), experimented on the concrete mixes with and without inclusion of hooked steel fibers in varying fractions and aspect ratio to evaluate the bond strength. Results clearly indicated that steel fibers play a significant role in enhancing the bond strength and ductility of concrete.

III. MATERIALS USED

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.

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.

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.

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.

Fig. 1 Class F Fly Ash

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.

Fig. 2 Metakaoline

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.

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%.

Water

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

IV. RESULTS & DISCUSSIONS

Compressive Strength Results

<u>28 days compressive strength results:</u>

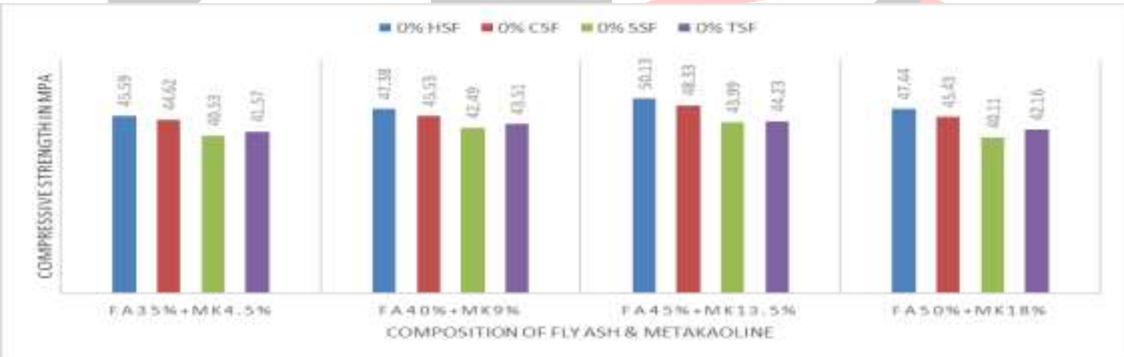

Fig 3: Compressive strength results for concrete mixes composed of various substitutions of FA+MK without any inclusion of steel fibers

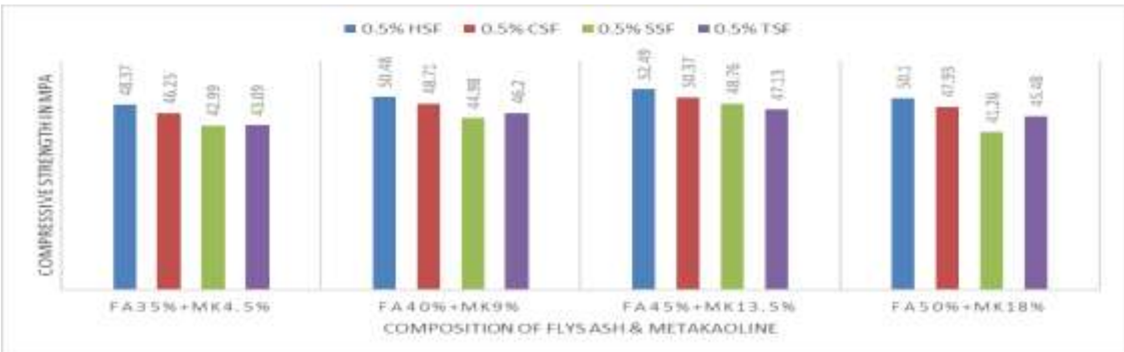

Fig. 4: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 0.5% HSF, CSF, SSF & TSF

Fig 5: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1% HSF, CSF, SSF & TSF

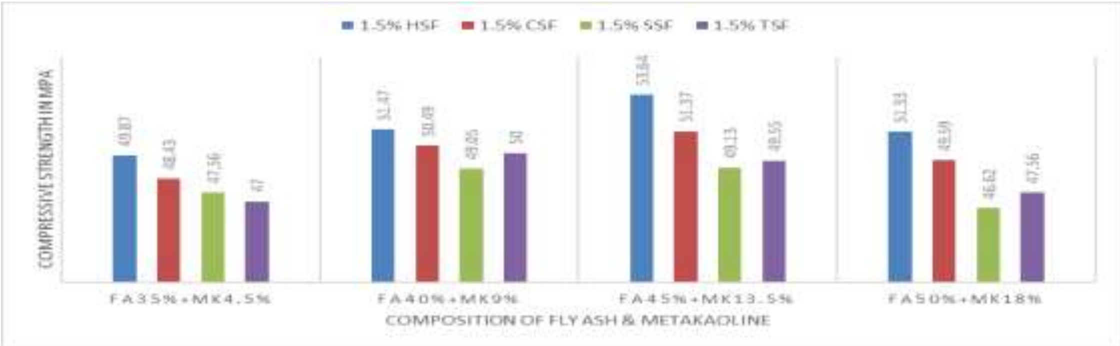

Fig 6: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1.5% HSF, CSF, SSF & TSF

56 days compressive strength results:

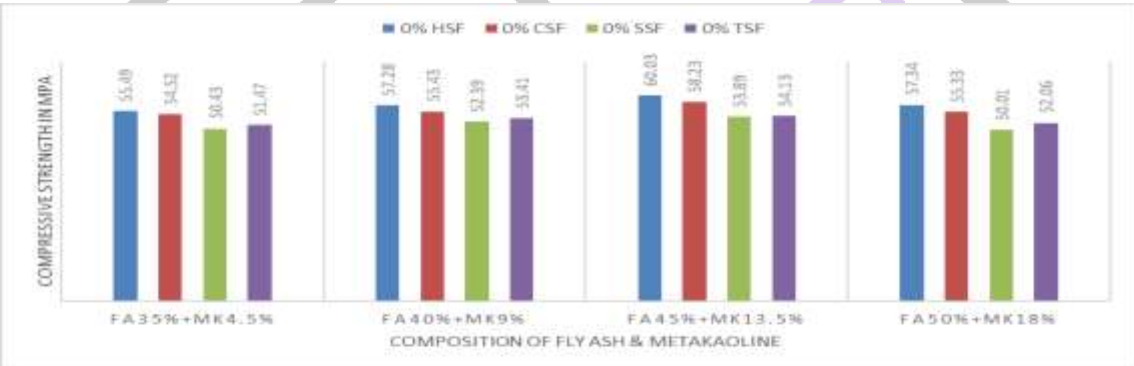

Fig 7: Compressive strength results for concrete mixes composed of various substitutions of FA+MK without any inclusion of steel fibers.

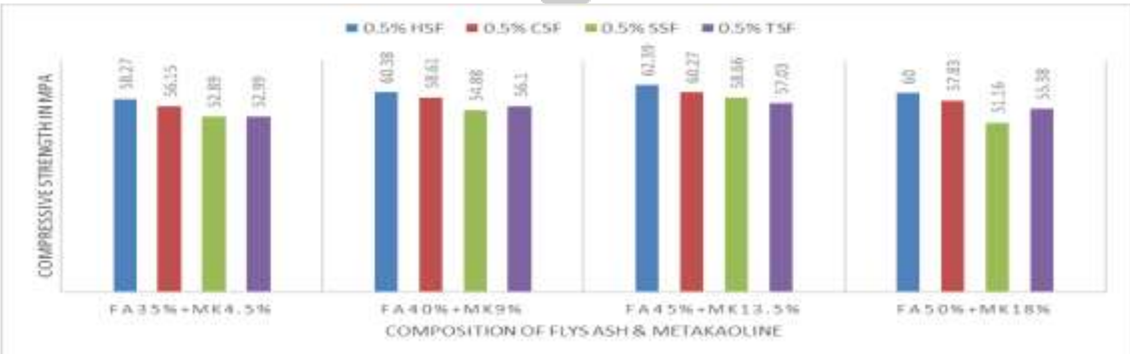

Fig 8: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 0.5% HSF, CSF, SSF & TSF

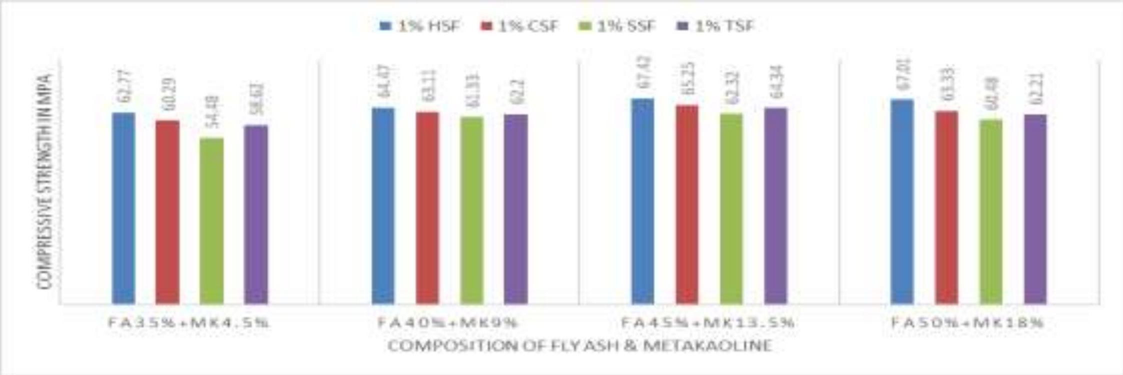

Fig 9: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1% HSF, CSF, SSF & TSF

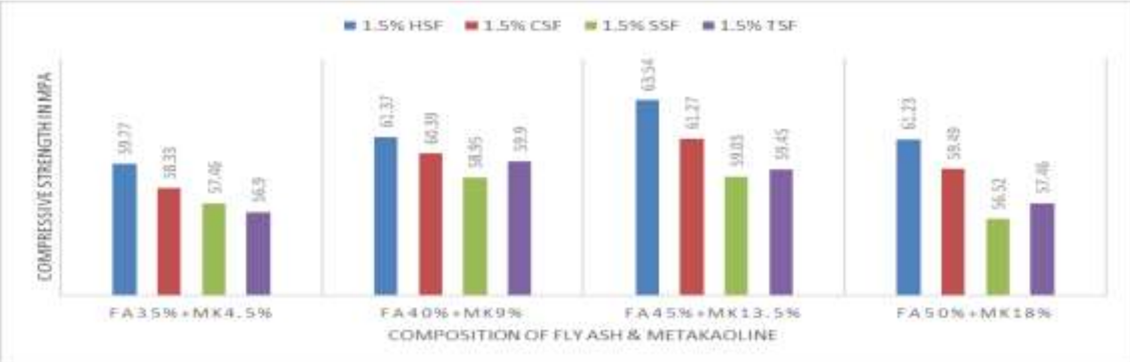

Fig 10: Compressive strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1.5% HSF, CSF, SSF & TSF

Discussions:

Compressive strength results were obtained for all the compositions of concrete mix, modified by fly ash (FA) and metakaoline (MK), incorporated with four types of steel fibers for 28 and 56 days curing duration and are represented clearly in the form of graphs above. A mix of FA25%+MK13.5% with 1% inclusion of hooked steel fibers produced the highest compressive strength of 57.52 MPa for 28 days curing and 67.42 MPa for 56 days curing period, followed by crimped steel fibers, then twisted steel fibers and lastly by straight steel fibers for the same composition. The least compressive strength of 46.62 MPa for 28 days curing and 56.52 MPa for 56 days was exhibited by a mix FA30%+MK18% with 1.5% inclusion of straight steel fibers. Hence, it is evident that FA25%+MK13.5% mix, strengthened with hooked steel fibers performed significantly better compared to other mixes. And hooked steel fibers imparted a huge gain in the compressive performance of all concrete mixes compared to all other steel fibers and straight steel fibers showed the least performance.

Flexural Strength Results:

<u>28 days Flexural strength results</u>:

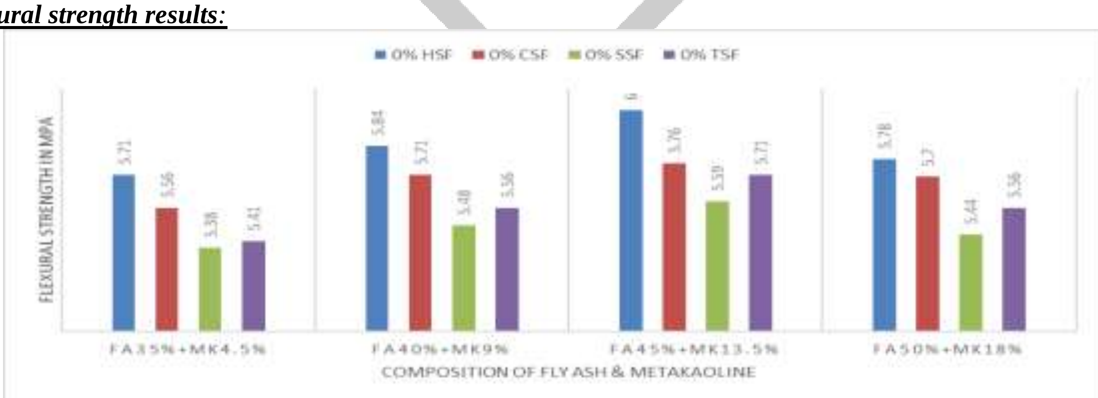

Fig 11: Flexural strength results for concrete mixes composed of various substitutions of FA+MK without any inclusion of steel fibers.

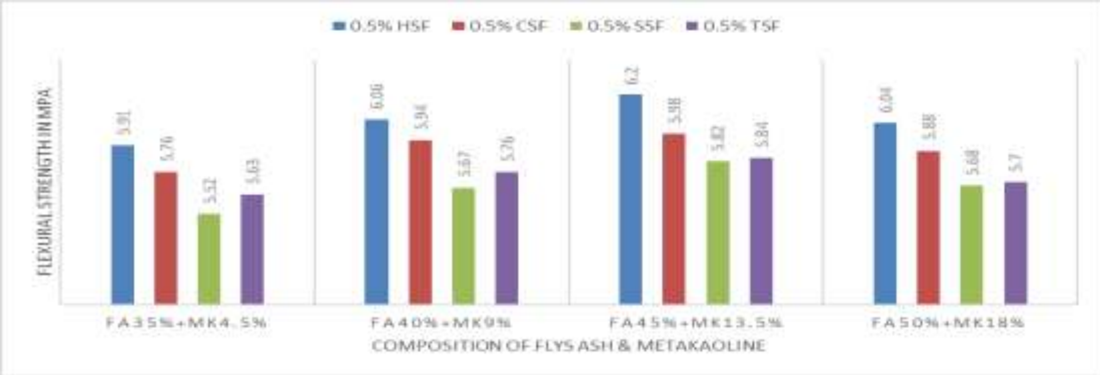

Fig 12: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 0.5% HSF, CSF, SSF & TSF

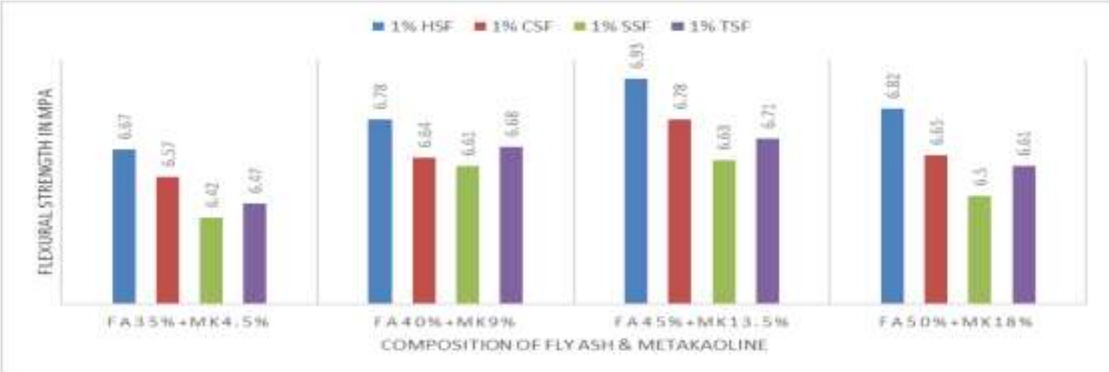

Fig 13: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1% HSF, CSF, SSF & TSF

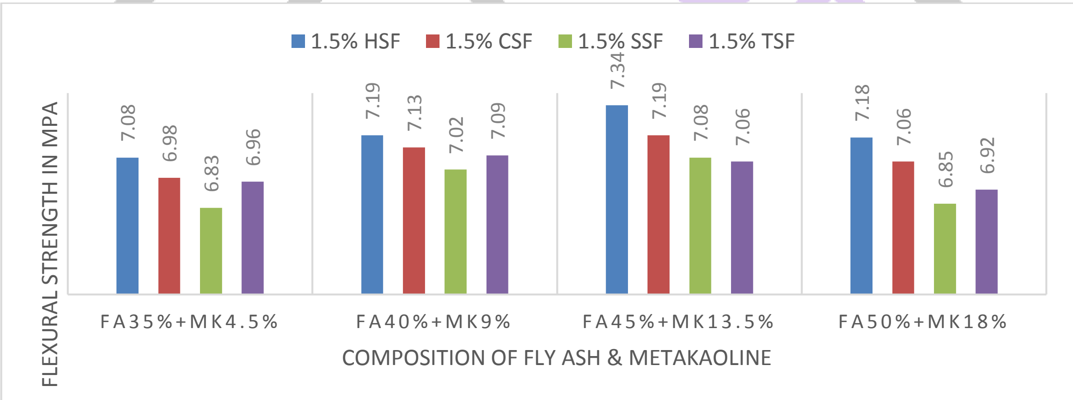

Fig 14: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1.5% HSF, CSF, SSF & TSF

56 days Flexural strength results:

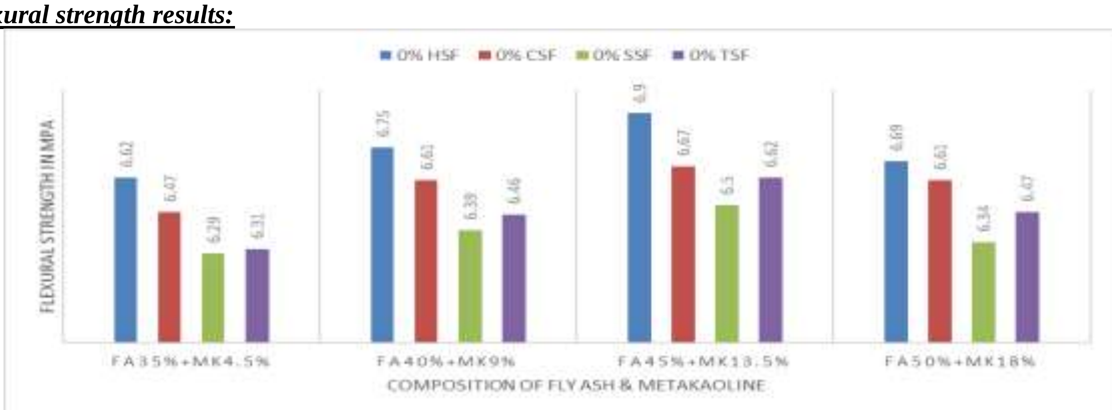

Fig 15: Flexural strength results for concrete mixes composed of various substitutions of FA+MK without any inclusion of steel fibers.

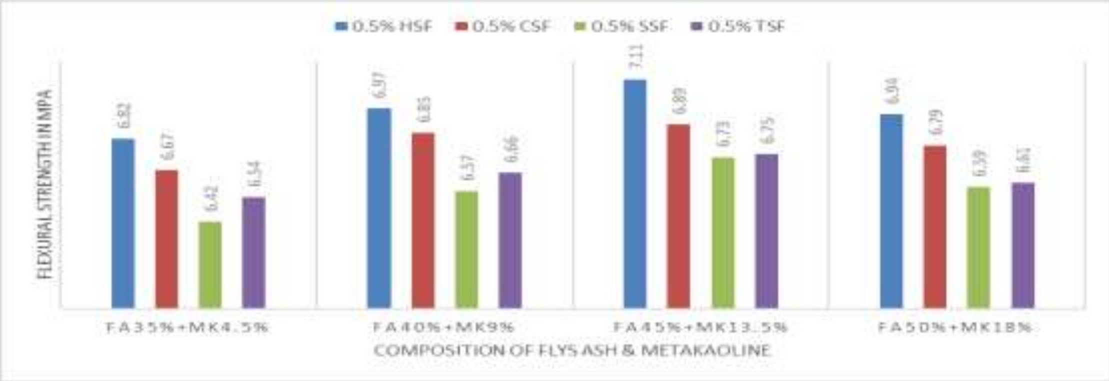

Fig 16: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 0.5% HSF, CSF, SSF & TSF

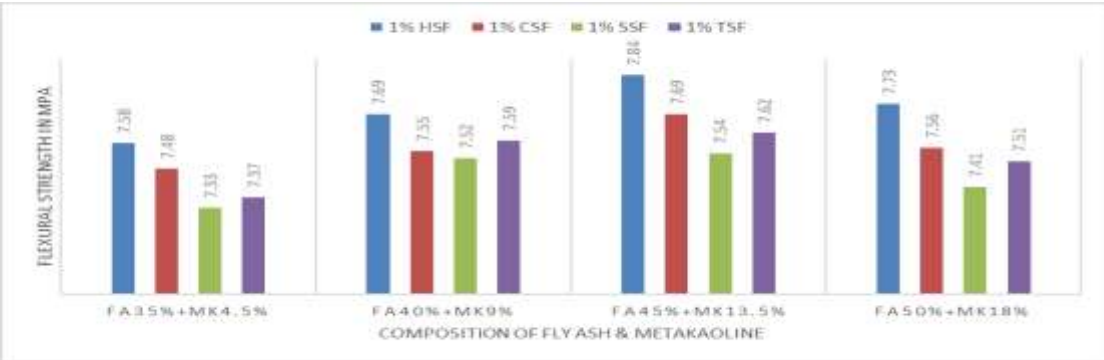

Fig 17: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1% HSF, CSF, SSF & TSF

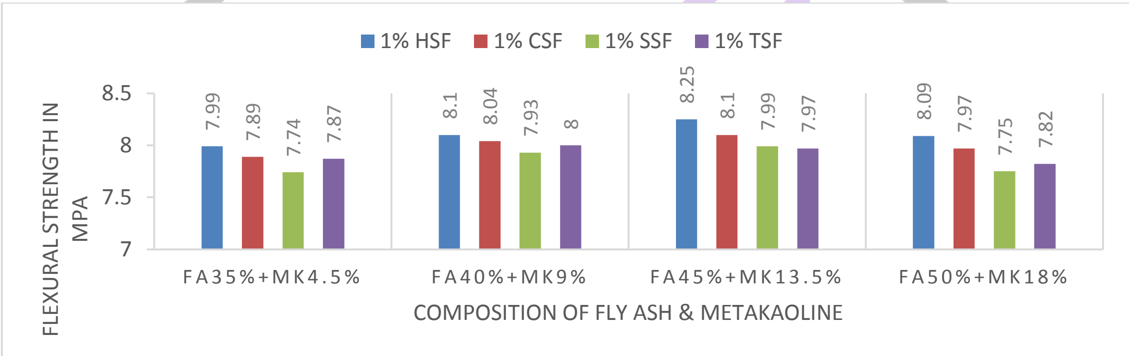

Fig 18: Flexural strength results for concrete mixes composed of various substitutions of FA+MK reinforced with 1.5% HSF, CSF, SSF & TSF

Discussions:

Flexural strength results were evaluated for all the compositions of concrete mix, modified by fly ash (FA) and metakaoline (MK), incorporated with four variants of steel fibers for 28 and 56 days curing duration and are represented clearly in the form of graphs above. A mix of FA25%+MK13.5% with 1% reinforcement of hooked steel fibers produced the maximum flexural strength of 7.34 MPa for 28 days curing and 8.25 MPa for 56 days curing period, followed by crimped steel fibers, then twisted steel fibers and lastly by straight steel fibers for the same composition. The least flexural strength of 5.44 MPa for 28 days curing and 6.34 MPa for 56 days was exhibited by a mix FA30%+MK18% with 0% inclusion of straight steel fibers. Therefore, it is evident that FA25%+MK13.5% mix, strengthened with hooked steel fibers performed significantly better compared to other mixes overall. And hooked steel fibers imparted a huge gain in the flexural performance of all concrete mixes compared to all other steel fibers and straight steel fibers showed the least performance.

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. Inclusion of hooked steel fibers in concrete compositions contributed excellent overall performance and proved to be the most efficient fiber among all fibers
7. Straight steel fibers exhibited least performance in terms of compressive and flexural among all other fibers.

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