International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 9 Issue 1 ǁ 2021 ǁ PP. 76-84

Influence of Metakaolin on the Behaviour of Hybrid Fibre Reinforced Concrete

(M. Jayasri* and H. Jane Helena**)
(Research Scholar,** Professor, Division of Structural Engineering, Dept. of Civil Engg., Anna University, Ch-25)*

ABSTRACT
This paper presents the results of an experimental investigation on the mechanical properties of structural concrete using Steel fibre (SF), Polypropylene fibre (PF) and Metakaolin (MK).The effects of these fibres and MK on various properties of M30 grade concrete are studied. MK Steel fibre content and Polypropylene fibre content were varied in percentage by weight of cement. All the specimens were water cured and tested after 28 days. It is seen that significant improvement in the structural performance of concrete is achieved by the addition of 15% MK in normal concrete. Hybrid fibre reinforced concrete (HFRC) reduces the chances of brittleness by arresting the micro and macro cracks. An increase of 28.5% was observed for 28 days compressive strength. Noticeable reduction in compressive strength was observed with increasing the percentage of MK beyond 15%.

Date of Submission: 12-01-2021 Date of acceptance: 27-01-2021

I. INTRODUCTION

Metakaolin(MK) is the anhydrous calcined form of the clay mineral kaolinite. Minerals that are rich in kaolinite are known as china clay (or) kaolin. MK is commonly used in the production of ceramics, but it is also used as cement replacement in concrete. It is prepared by calcination of kaolin(clay mineral) at temperature of 650ºC-800ºC.It has chemical formula of $Al_2O_3.2SiO_2.2H_2O$. It reacts quickly and reduces the diffusion coefficient compared with Plain Portland cement due to the small particle size and high surface area. It is eco-friendly. When cement is partially replaced with MK, it reacts with calcium hydroxide and results in extra C-S-H gel, which is the sole cause for strength development in cement and cement based concrete.

It reduces the size of pores in cement paste by transforming finer particles into discontinuous pores. MK increases compressive strength and flexural strength. It reduces the efflorescence in concrete. It reduces the heat of hydration leading to shrinkage and crack control due to pozzolanic activity. The details of a few selected research work carried out worldwide in this area are discussed below

Guneyisi et al (2014) conducted experimental study on mechanical properties of plain and metakaolin (MK) concrete with and without steel fibre. The results revealed that incorporation of MK and utilization of different types of steel fibres significantly improved the mechanical properties of the concrete irrespective of water binder ratio. **Vu et al** (2001) studied the effect of partial replacement of Portland cement with calcined form of kaolin in concrete on compressive strength as well as durability characteristic of concrete. The highest value of compressive strength was obtained at 25% replacement. **Gruber et al** (2001) conducted experiments on highly reactive metakaolin with the objective of increasing the durability of concrete. It is observed that MK substantially reduces chloride ion penetration in concrete and improves the long term durability of concrete.

Dawood et al (2012) investigated the mechanical properties of hybrid fibre. Hybridizations of steel fibres, palm fibres, and synthetic fibres (bar chip) by incorporating them with high strength flowing concrete (HSFC) to determine the density, compressive strength, split tensile strength, static modulus of elasticity, flexural strength, toughness indices, and impact-load test was studied. The results demonstrate that the hybridizations of such fibers enhance the flexural toughness and tensile strength of the HSFC.

Yap et al (2014) studied the hybridization of steel–polypropylene fibre and reported the improvements in both the mechanical and ductility characteristics of concrete.

Zheng et al (2012) investigated the compressive properties and microstructures of reactive powder concrete (RPC) mixed with steel fibre and polypropylene fibre after exposure to 20–900ºCelsius. Compared with normal-strength and high-strength concrete, the hybrid fiber-reinforced RPC has excellent capacity in resistance to high temperature.

Rashiddadash et al (2014) observed that fibre reinforced concrete has been widely used due to its advantages over plain concrete. It can be an appropriate material for the repair of structures in a variety of situations. Results showed that metakaolin with highest substitution of cement has the best performance for mechanical properties of concrete. However, replacing pumice into the specimens had negative effect on the mechanical properties.**Ramujee** (2013) observed the results of the strength properties of Polypropylene fibre reinforced concrete. It is observed that both compressive and tensile strength increased for upto 1.5 % fibre content after their strength decreased. **Vibhuti et al** (2013) reported the effect of addition of mono fibres and hybrid fibres on the mechanical properties of concrete mixture. The results show that hybrid fibres improve the compressive strength marginally as compared to mono fibres. 17% increase in the compressive strength was observed as a result of hybridization. Also, hybridization boosted the split tensile strength and flexural strength by 52.87% and 34.25% respectively. **Yilmaz (2020)** reported that the rate of substitution of metakaolin increases during the hydration process when the amount of portlandite was decreased. **Radhikesh et.al. (2020)** showed that cement replacement with 10% fly ash, 3% metakaolin and 0.2% recron 3s fiber enhanced the mechanical properties of concrete.

Rakesh (2019) states that the workability becomes higher with higher percentage of recycled coarse aggregate but it slightly reduces when metakaolin is used. **Gildas et. al.(2018)** reported that lower water cement ratio improves short term strength and resistance to carbonation.

Sujiiavanich et. al. (2017) concluded that the proportion of cement, metakaolin, flyash as 80:10:10 enhances the improvement of slump, slump loss, and strength.

Norhasni et. al. (2016) concluded that Nano metakaolin UHPC mix contributes to a low workability effect as compared to OPC and metakaolin .

From the literature it is seen that studies can be carried out using rice husk ash, lime, fly ash, bagasse ash, rice straw as replacement for cement. Therefore, this work aims to determine the basic mechanical properties of influence of metakaolin in hybrid fiber-reinforced concrete. The two fibers used are steel fibre and polypropylene fibre. The compressive strength, split-tensile strength, flexural strength, impact strength and stress-strain behavior are studied. The main aim of the study is to find the optimum replacement dosage of Portland cement by metakaolin and to understand the combined effect of metakaolin and hybrid fibers on various mechanical properties of concrete.

The various tests considered for investigation are compressive strength, split tensile strength, flexural strength and impact strength. Cubes of 150mm for compressive strength, Cylinder of size 150 mm diameters × 300mm length for split tensile strength, beams of 100×100×500mm for flexural strength, Disc of size 150×80mm for impact strength were cast.

II. MATERIALS USED IN CONCRETE

Cement

OPC of 53 grade confirming to IS 12269-1987 was used in this investigation. The specific gravity of cement was 3.15.

Coarse aggregate

Crushed stone metal with a maximum size of 20mm from a local source having the specific gravity of 2.7 conforming to IS 383-1970 was used.

Fine aggregate

Locally available river sand passing through 4.75mm IS sieve conforming to grading zone-II of IS 383-1970 was used. The specific gravity of fine aggregate was 2.64.

Metakaolin

Metakaolin is not a by-product. It is obtained by the calcination of pure or refined kaolinite clay at a temperature between 650ºC and 850ºC, followed by grinding to achieve a fineness of 700-900m^2/kg.MK is a high quality pozzolanic material, which is blended with cement in order to improve the durability of concrete. When it is used in concrete, it will find the void space between cement particles resulting in a more impermeable concrete.

Metakaolin is a relatively new material in the concrete industry, it is effective in increasing the strength, reducing sulphate attack and improving air void network. Pozzolanic reactions change the microstructure of concrete and chemistry of hydration products by consuming the released calcium hydroxide (CH) and production of additional calcium silicate hydrate (C-S-H), resulting in an increased strength and reduced porosity and therefore improved durability. The physical characteristics of these binders were determined as specified in IS 4031(1996), Tables 1 and 2 show their chemical and physical characteristics.

Fibres

Steel fibres(SF) strengthen concrete by resisting tensile cracking. Reinforcing concrete with steel fibres results in durable concrete with a high flexural strength, improved abrasion, spalling and impact resistance. It is a more economical design alternative. Polypropylene fibres(PF) is a synthetic fibre. It is light weight,strong,hydrophobic,flexible and it has low thermal conductivity.

Table1 Chemical constituent of Metakaolin

Chemicals	Percentage of mass
Sio_2	52.86
Cao	0.28
Mgo	0.20
FeO_3	0.45
Al_2O_3	44.10
Na_2O	0.25
K_2O	0.20
TiO_2	0.36
Loss on Ignition	0.85
Ret. On 90 micron	0.5
Oil Absorption	64.00ml/100gm
Water Absorption	66.80ml/100gm

Table 2 Physical Properties of materials

(a).Cement

Grade	53
Specific gravity	3.15
Fineness percentage	2

(b).Fine aggregate

Specific gravity	2.64
Fineness modulus	2.2
Bulk density	1635kg/m^3
Loose density	1512kg/m^3

(c).Coarse aggregate

Specific gravity	2.74
Fineness modulus	6.5
Bulk density	1530kg/m^3
Loose density	1385kg/m^3

(d).Steel fibres

Specific gravity	7.8
Form	Straight
End Anchorage	Hooked
Surface	Plane
Diameter	1mm
Length	50mm

(e).Polypropylene fibres

Specific gravity	0.9
Form	Straight
Surface	Plane
Size	10mm

The particle size distribution of coarse aggregate is shown in Fig.1.

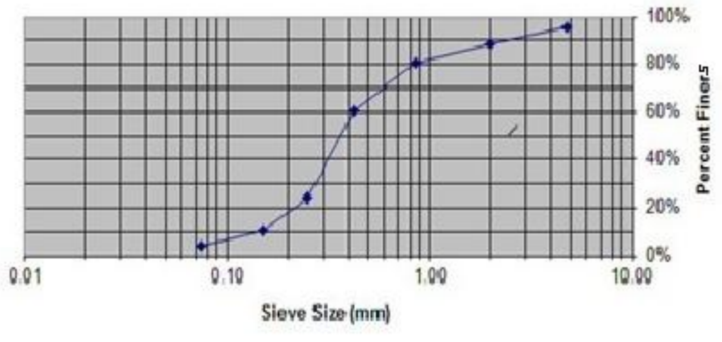

Fig.1.Particle size distribution of coarse aggregate

MIX DESIGN

HFRC mixes were proportioned using the methodology provided in IS-10262(2009).41 HFRC mixes was cast as two series. One series consists of fibre and other was made with fibre and metakaolin. The water/binder ratio was kept as 0.45. In both the series of HFRC,0.9% steel fibres and 0.1% polypropylene fibres were added and cement was replaced by 10-20% of Metakaolin. The details of mix design is given in Table.3.

Table.3.Mix Proportions in Per m^3

Mix ID	Water (litre)	Steel fibre(kg)	Polypropylene fibre(kg)	Metakaolin(kg)	Cement (kg)	Fine Aggregate (kg)	Coarse aggregate(kg)
Control mix	197	-	-	-	437.78	648.69	1138
HFRC-C	197	3.94	0.43	-	433.41		
MK5	197	3.94	0.43	21.89	411.52		
MK10	197	3.94	0.43	43.78	389.63		
MK15	197	3.94	0.43	65.67	367.74		
MK20	197	3.94	0.43	87.56	345.85		

EXPERIMENTAL INVESTIGATION

In order to assess the behaviour of metakaolin in hybrid fibre reinforced concrete, detailed experimental investigation was carried out to assess the compressive strength, split tensile strength and impact strength. Fibres used are shown in Fig.2

(a).Polypropylene (b)Steel

Fig . 2 . Fibres used

MECHANICAL PROPERTIES

To assess the mechanical properties, 36 cylinders, 54 cubes, and 18 beams were tested. The mechanical properties such as compressive strength, split tensile strength, flexural strength, and impact strength were performed as specified in Table 4.

Table 4.Details of Mechanical Property Tests

Experiments performed	In accordance with	Specimen type	Specimen size(mm)	No. of samples tested	Testing Ages(days)
Cube Compressive Strength	IS-516(1959)	Cube	150×150×150mm	18	3,7, and 28
Split Tensile Strength	ASTM-C496(1996)	Cylinder	150×300mm	12	7 and 28
Flexural Strength	ASTM-C78(2018)	Beam	100×100×500mm	6	28
Impact Strength	ASTM-D1505(2003)	Disc	150×80mm	5	28

III. RESULTS AND DISCUSSIONS

Cube compressive strength

The compressive strength result given in Fig.3 shows that all the Metakaolin incorporated concrete mixtures MK10,MK15, and MK20 exhibit higher strength than the control concrete in the early days of hydration :3,7 and 28 days.MK15 exhibits higher compressive strength on these days than MK10 and MK20 due to hybridization of steel. The compressive strength values of all the metakaolin incorporated concrete gradually increases to that of normal concrete at these days of curing. But there is a sudden decrease in the compressive strength values of MK20 at these days of curing. The graph of MK10 coincides with that normal concrete. MK 15 shows an increasing trend whereas MK 20 shows a sudden decrease as it has a detrimental effect on strength and efflorescence. This increase in compressive strength in MK15 is due to the pozzolanic reaction of silica of metakaolin with the cement hydrates forming strength enhancing C-S-H gel and alumina silicate hydrates such as stratlingite, hydrogarnet etc.

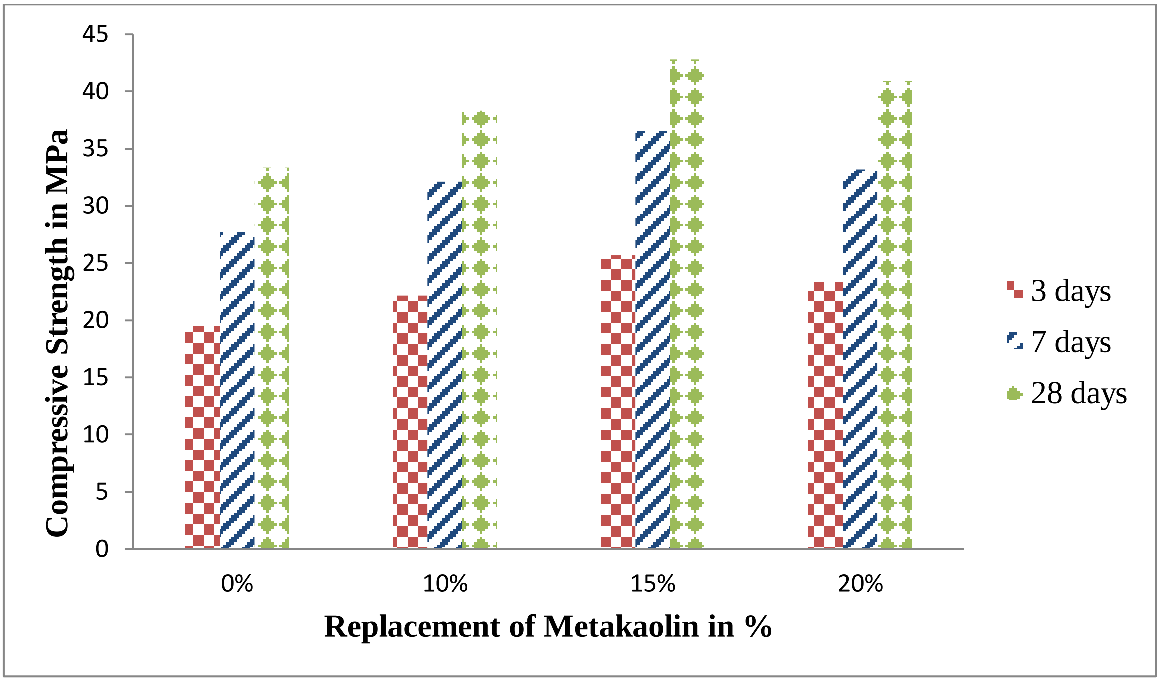

Fig 3. Cube Compressive Strength of HFRC

Split tensile strength

Fig.4 shows the split tensile strength value of all the mixes at 7 and 28 days and the Metakaolin(MK) mixes exhibited higher tensile strength value compared to normal concrete(NC) mix at 7 and 28 days. The tensile strength value follows the same trend as in compressive strength with MK10 and MK15 exhibiting values higher than NC at these days. It is seen from the results that similar to the compressive strength values the MK15 mix exhibited higher values compared to MK10 and MK20. Addition of steel fibre increases the tensile strength, however addition of low amount of polypropylene fibre enhances the flexibility and reduces the dispersion problem.MK20 shows that there is a slight decrease in strength compared to MK15 as there is no left out calcium hydroxide to react with Metakaolin beyond 15%.

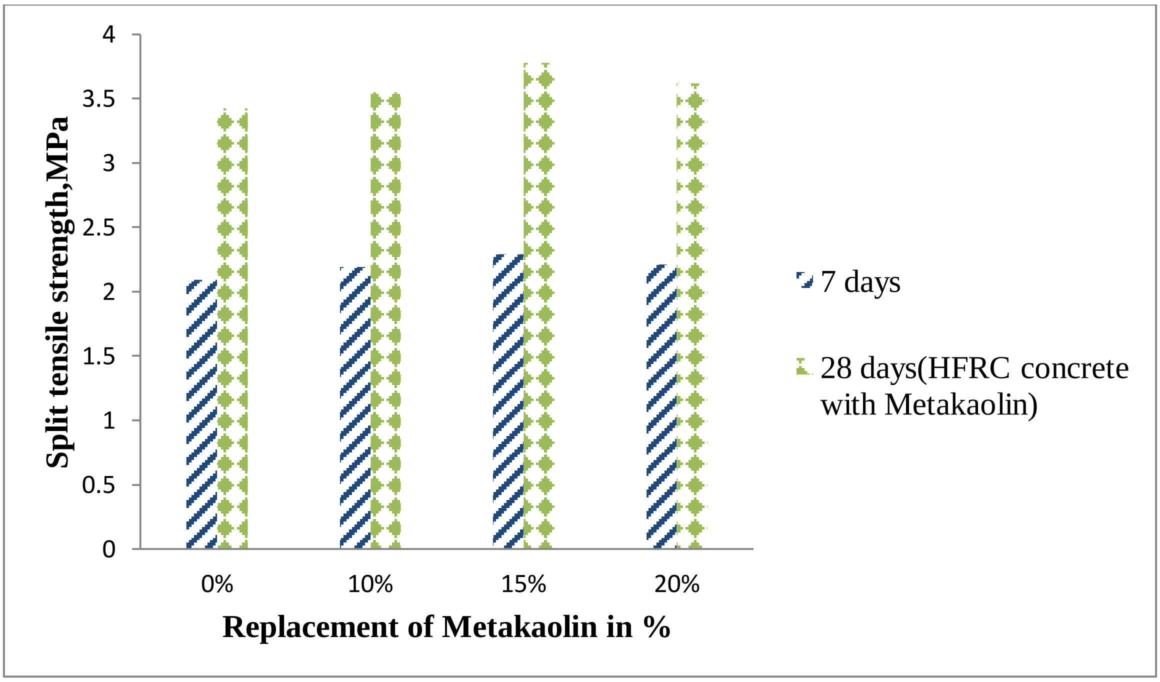

Fig. 4. Splitting Tensile Strength of HFRC

Flexural strength

Fig.5 shows the test setup for flexural test.Fig.6 shows the variation of results for flexural strength concrete with cement replacement by metakaolin at 28 days, It is clear that flexural strength of concrete with 15% cement replacement by metakaolin showed a higher value compared to control concrete for 28 days respectively. MK20 shows a sudden decrease in flexural strength compared to MK15. Flexural strength improves due to the addition of fibres in tension zone as the cracks are arrested and it provides additional energy absorption.

Fig . 5 . Flexural Strength Test

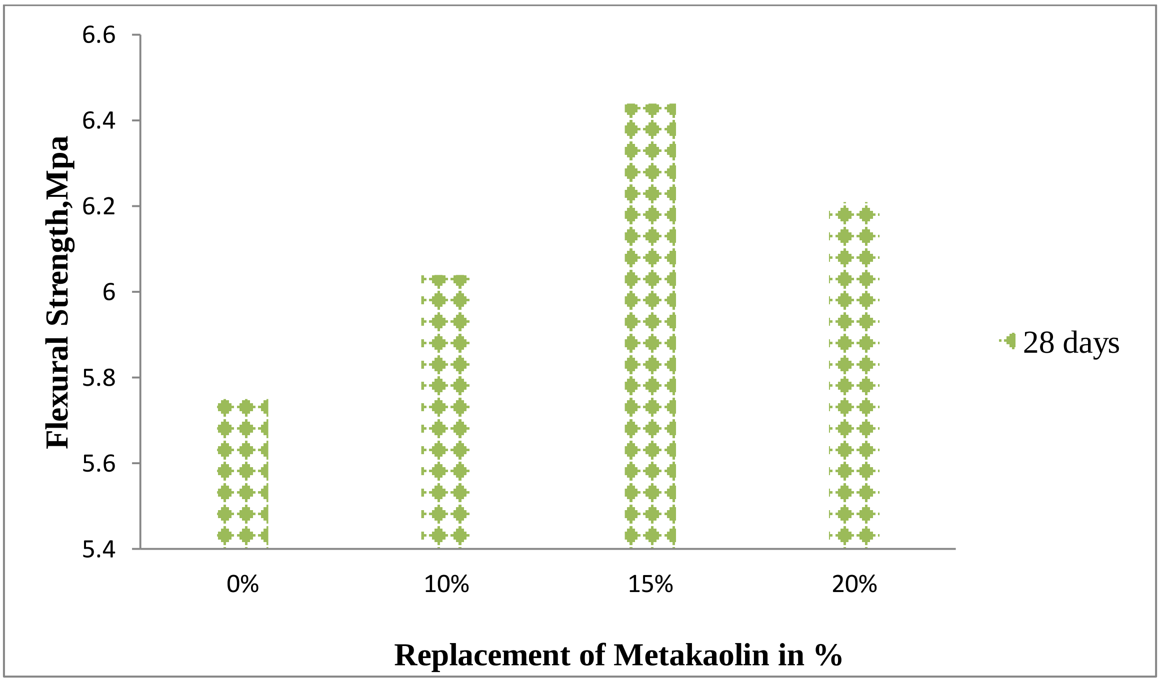

Fig 6.Flexural Strength for HFRC

Impact strength

Fig.7 shows the test setup for impact test. Fig.8 and Fig.9 show the impact strength test results for 28 days at just crack and failure respectively. There is a continuous increase in strength of MK10 and MK15 compared to normal concrete. It is clear that cement with 15% replacement of metakaolin shows a higher strength compared to other replacements. But there is a sudden decrease in strength beyond 15%. replacement level.

Fig. 7. Impact Test

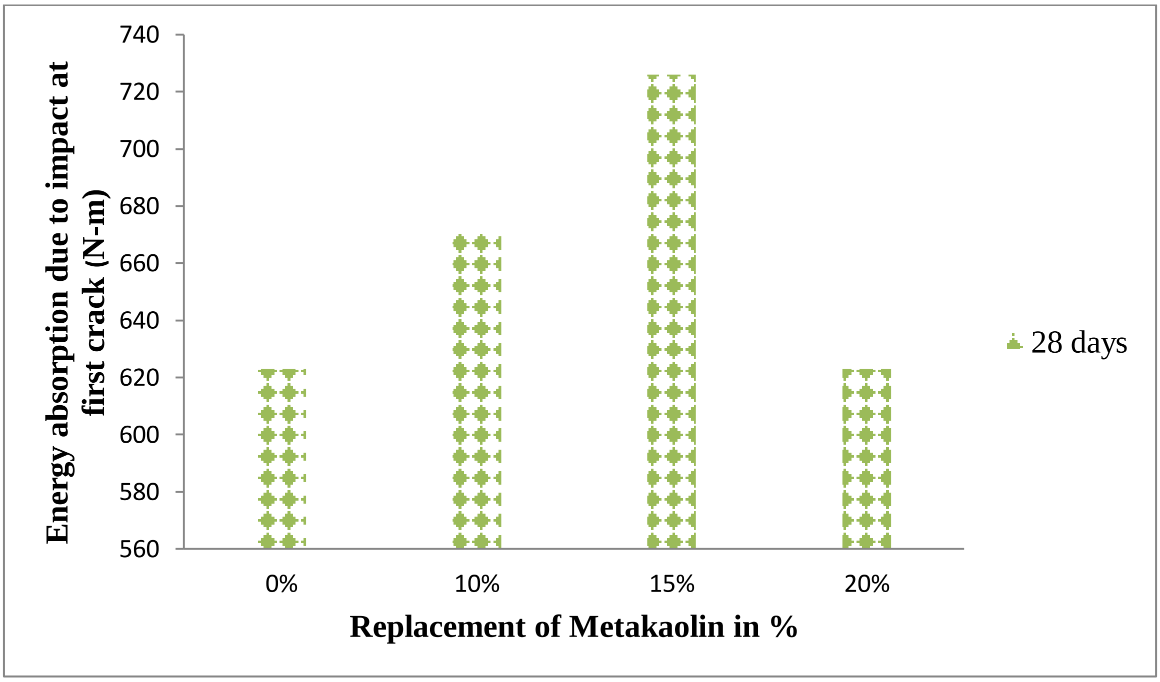

Fig 8.Impact strength variation at first crack

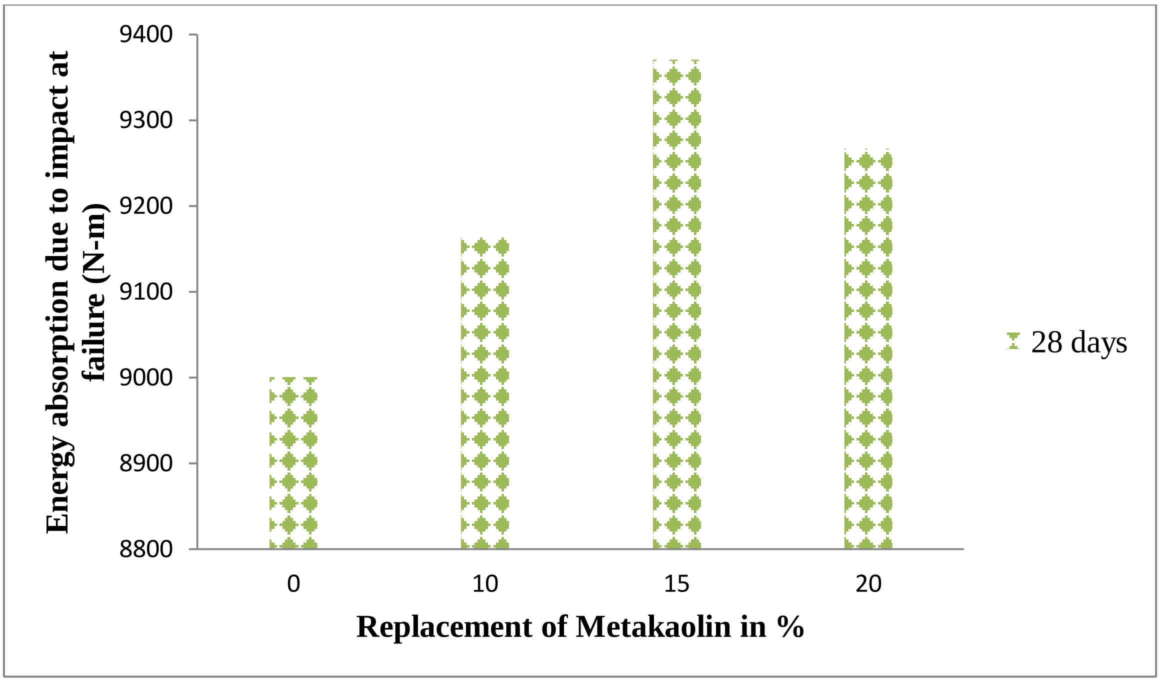

Fig.9.Impact strength variation at failure

IV. CONCLUSIONS

The percentages of steel and polypropylene fibers were kept constant. The cement was partially replaced by Metakaolin(MK). From the experiments carried out and interpretation of recorded results, the following conclusions are drawn.

- An increase in 28.5% was observed for 28 days compressive strength of specimen having 15% replacement of cement with MK by weight of cement. Noticeable reduction in compressive strength was observed with increasing the percentage of MK beyond 15%.
- The split tensile strength is found to increase by 10.25% whereas an increase of 12% was observed in flexural strength for 15% replacement of cement with MK by weight of cement.
- From the impact strength result, it is observed that energy absorption property was enhanced due to addition of fibres in concrete. Hybridization of steel and polypropylene fibres contributes to the improvement of mechanical properties of concrete by arresting micro and macro cracks.
- The utilization of supplementary cementitious material like MK can compensate the environmental and economic issues caused by cement production.

REFERENCES

[1]. D.D.Vu,P.Stroeven, V.B.Bui (2001), "Strength and durability aspects of calcined kaolin blended Portland cement mortar and concrete", *Cement and concrete composite*, Vol 23, pp.471-478.

[2]. Ekaterina Potapora et. al. (2019),"The effect of metakaolin on the processes of hydration and hardening of cement", *Materials today:Proceedings*", Vol.19 , pp.2193-2196.

[3]. Eethar Thanon Dawood,Mahyuddin Ramlin (2012), "Mechanical properties of high strength flowing concrete with hybrid fibers", *Construction and building materials*, Vol 28, pp.193-200

[4]. Erhan Guneyini,Mehmet Gesoglu,Arass Omer Mawlod Akoi,Kasmim Mermerdas(2014),"Combined effect of steel fiber and metakaolin incorporation on mechanical properties of concrete",*Composite:Part B*,Vol.56,pp.83-91

[5]. Gildas Medjigbodo et. al.(2018), "Hydration,shrinkage and durability of ternary binders containing Portland cement,limestone filler and metakaolin", *Construction and building materials*, Vol.183, pp.114-126

[6]. IS 10262-2009,"Recommended Guidelines for Concrete Mix Design"

[7]. K..A.gruber,Terry Ramlochan,Andrea Boddy,R.D.Hooton,M.D.A.Thomas(2001), "Increasing concrete durability with high reactivity metakaolin", *Cement and concrete composite*, Vol.23, pp.479-484.

[8]. K.Srinivasa Rao,S.Rakesh Kumar,A.Laxmi Narayana (2013), "Comparison of performance of standard concrete and fiber reinforced standard concrete exposed to elevated temperatures" *American Journal of Engineering Research*, Vol 2, pp.20-26

[9]. Kirk Vance,Aditya Kumar,Gaurav Sant,Narayanan Neithalath(2013), "The rheological properties of ternary binders containing Portland cement,limestone and metakaokin or fly ash", *Cement and Concrete Research*, Vol 52, pp.196-207.

[10]. Kolli.Ramujee(2013), "Strength properties of polypropylene fiber reinforced concrete", *International journal of innovative research in science,Engineering and Technology*, Vol.2, pp.3409-3413

[11]. M.P.Muhd Norhasni et. al.(2016), "Inclusion of nano metakaolin as additive in ultra-high performance concrete", *Construction and building materials*, Vol.127, pp.167-175

[12]. M.Tamilselvi,Dr.T.S.Thandavamoorthy(2013), "Studies on the properties of steel and polypropylene fiber reinforced concrete without any admixture", *International journal of engineering and innovative technology(IJEIT)*, Vol 3, pp.411-416

[13]. Pantea Rashiddadash,Ali Akbar Ramezanianpour,Mahdi Mahdikhani (2014) ”Experimental investigation on flexural toughness of hybrid fiber reinforced concrete (HFRC) containing metakaolin and pumice’, *Construction and building materials*, Vol.51, pp.313-320

[14]. Radhikesh.P.Nanda et. al,(2020) ”Influence of metakaolin and recron 3s fiber on mechanical properties of fly ash replaced concrete”, *Construction and building materials*, Vol.263, pp.120949.

[15]. Rajarajeshwari BVibhuti,radhakrishna,aravind N(2013), ”Studies on the properties of steel and polypropylene fiber reinforced vconcrete without any admixture”, *International journal of research in Engineering and technology*, Vol.2, pp.244-247

[16]. Rakesh Muduli(2019), ”Effect of incorporation of metakaolin and recycled coarse aggregate on properties of concrete”, *Journal of cleaner production*, vol.209, pp.398-414.

[17]. R.Yu,P.Spiez,H.J.H.Brouwers(2014), ”Static properties and impact resistance of a green ultra-high performance hybrid fiber reinforced concrete(UHGPHFRC),Experiments and modeling”, *Construction and building materials*, Vol.68, pp.158-171.

[18]. S.Sujjavanich et. al.(2017), ”Synergistic effect of metakaolin and flyash on properties of concrete”, *Construction and building materials*, Vol.155, pp.830-837

[19]. Soon Poh Yap,Chun HooiBu,U.Johnson.Alengaram,KimHung Mo,Mohd zamin Jumaat (2014), ”Flexural toughness characteristics of steel-polypropylene hybrid fiber reinforced oil palm shell concrete”, *Materials and Design*, Vol.57, pp.652-659

[20]. [20] Seung Poh Yap,Dong joo kim,gum sung ryu,Kyung taek koh(2012), ”Flexural toughness characteristics of steel-polypropylene hybrid fiber reinforced oil palm shell concrete”, *Cement and concrete composite*, Vol.34, pp.172-184

[21]. V.Bhikshma and K.Manipal (2012), ”Study on mechanical properties of recycled aggregate concrete containing steel fibers”, *Asian journal of civil engineering(Building and housing*, Vol.13, pp.155-164

[22]. Wenzhong Zheng,Haiyan Li,ying Wang(2001), ”Compressive behavior of hybrid fiber reinforced reactive powder concrete after high temperature” *Cement and concrete composite*, Vol.23, pp.471-478

[23]. Yilmaz Kocak(2020), ”Effect of metakaolin on the hydration development of Portland-composite cement”, *Journal of building engineering*, Vol.31, pp.101419