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Experimental Study on Partial Replacement of Cement with Metakaolin Incorporated With the Comparison of Artificial and Natural Fiber Addition

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Abstract: Concrete is the most extensively used construction material. Maintenance and repair of reinforced concrete structures is a growing problem involving significant expenditure. Also the second most consumed product in the world is cement. It contributes nearly 7% of the global carbon dioxide emission. This project mainly aims at the study of effect of partial replacement of cement with metakaolin and fibers addition on concrete of M35 grade. In this mainly the comparison of artificial fiber (Nylon fiber) and natural fiber (Sisal fiber) is done. The project is conducted on two steps. First various tests were conducted on hardened concrete with varying percentage of metakaolin (5%, 10%, 15%, 20%) and finding out the optimum percentage. Second with this, various tests conducted separately on hardened concrete with varying percentage of nylon fiber (0.5%, 1%, and 1.5%) and sisal fiber (0.5%, 1%, and 1.5%) and finding out their optimum percentage.

Test results reveal that metakaolin possess very good cementitious properties and it becomes very good alternative for cement. 20% is obtained as optimum percentage of metakaolin.In case of fibers 1% is obtained as optimum for both nylon and sisal fiber. On comparing nylon fiber reinforce concrete possess more strength than sisal fiber reinforced concrete. Hence artificial fiber is better than natural fiber.

Keywords: Metakaolin, Nylon Fiber, Sisal Fiber

I. INTRODUCTION

Concrete is the most widely used construction material in the world and ordinary Portland cement (OPC) is the major ingredient used in concrete. The production of cement releases large amount of carbon dioxide (CO2) to the atmosphere that significantly contributes to greenhouse gas emissions. It is estimated that one ton of CO2 is released into the atmosphere for every ton of OPC produced. Also the low tensile strength of the concrete material is the basic concept of reinforced concrete. In this study, partial replacement of cement with metakaolin is used. Also a comparison between nylon and sisal fiber is used.

A. Metakaolin

The raw material that is used in the manufacture of metakaolin is kaolin clay. Kaolin is a fine, white clay that is using from ancient times in the manufacture of porcelain. The prefix meta that is used to express change. Compared to other pozzolans raw metakaolin is highly reactive. Metakaolin is a useful admixture of cement and concrete applications. Partial replacement of metakaolin in mixture gives favorable engineering properties like compressive and tensile strength. It is the finest substance and has size of particle as 3 micrometer. Metakaolin was obtained from Kerala Ceramics Limited, Kundara and was light yellow in colour.

B. Nylon Fiber and Sisal Fiber

Nylon is a generic designation for a family of synthetic polymers, based on aliphatic or semi-aromatic polyamides. Nylon is a thermoplastic silky material that can be melt-processed into fibers, films or shapes. Nylon was the first commercially successful synthetic thermoplastic polymer. Nylon is a man-made synthetic fiber that is strong while very light in weight, properties that lead to a wide variety of uses, such as fabric, rope and luggage. Nylon possesses many properties that make it a very useful fiber in many applications. It is very strong and elastic also easy to wash, and can usually be washed with similar items and does not typically require specialty laundering arrangements. Nylon dries rather quickly and it retains its shape rather well after laundering, which ensures longevity of the garment. Nylon fiber is very responsive and resilient as well as relatively resistant to heat, UV rays and chemicals. The sisal fiber is obtained from Vruksha Composites and Services, Chennai.

Sisal fiber is one of the most widely used natural fibers and is very easily cultivated. It has short renewal times and grows wild in the hedges of fields and railway tracks. Nearly 4.5 million tons of sisal fiber is produced every year throughout the world. Tanzania and Brazil are the two main producing countries. Sisal fiber is a hard fiber extracted from the leaves of the sisal plant (Agave sisalana). Though native to tropical and sub-tropical North and South America, sisal plant is now widely grown in tropical countries of Africa, the West Indies and the Far East. Sisal fibers are extracted from the leaves. A sisal plant produces about 200±250 leaves and each leaf contains 1000±1200 fiber bundles which are composed of 4% fiber, 0.75% cuticle, 8%dry matter and 87.25% water. So normally a leaf weighing about 600 g will yield about 3% by weight of fiber with each leaf containing about 1000 fibers.

II. NEED FOR THE STUDY

Concrete is the most widely used construction material in the world and OPC is the major ingredient used in concrete. The production of cement releases large amount of carbon dioxide to the atmosphere that significantly contribute to greenhouse gas emissions. Hence metakaolin can be used as an alternative for cement. Concrete is relatively strong in compression and weak in tension and tends to be brittle in behavior. The weakness in tension can be overcome by providing steel bars and to some extent by the mixing of a sufficient volume of certain fibers and these fibers are used s secondary material. Hence nylon and sisal fiber is used and a comparison is made between them.

III. SCOPE AND OBJECTIVES

The scope of the present study is to investigate the properties on concrete by partial replacement of cement by metakaolin followed by nylon and sisal fiber addition and made a comparison between these. The objectives are,

A. To estimate the optimum percentage of metakaolin, nylon and sisal fiber
B. To made a comparison between nylon and sisal fiber.

IV. METHODOLOGY

In this study M35 grade concrete is used. In this materials are cement, fine and coarse aggregate, metakaolin, nylon and sisal fiber. The project conducted on two tier. In first tier cement is partially replaced with metakaolin in varying percentage. The varying percentages are 5%, 10%, 15% and 20%.The concrete blocks are casted and compressive strength and flexural strength test is conducted. Based on these optimum percentage is found out.

In second tier based on the optimum percentage of matakaolin,nylon and sisal fiber is added separately in varying percentage to different concrete mix and concrete blocks are casted. The percentages used are 0.5%, 1% and 1.5%.Based on the tests optimum percentage is found out. Durability properties are found out by carbonation, bulk diffusion and sulphate resistence tests. Ultimate load of control beam and optimum specimen is found out by load deflection test.

A. Compression Test

The compressive strength of any material is defined as the resistance to failure under the action of compressive forces. Especially for concrete, compressive strength is an important parameter to determine the performance of the material during service conditions. Out of many test applied to the concrete, this is the utmost important which gives an idea about all the characteristics of concrete.

B. Flexural Strength Test

Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending. It will measure by breaking load under two point loading on concrete beams.

C. Split Tensile Strength Test

The tensile strength of concrete is one of the basic and important properties. Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack

D. Durability

Durability of concrete may be defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. The tests conducting on the specimen are bulk diffusion,carbonation and sulphate resistence.

1) *Bulk Diffusion Test:* In bulk diffusion test, cylinder of 100 mm diameter and 200mm length will be used as test specimen. After 7 days of water curing, the concrete specimens will be exposed to 1.8 Molar NaCl solution for 56 days. After 56 days and of exposure the specimens will be split by applying splitting tensile force. To the split face, 0.1 Molar Silver Nitrate ($AgNO3$) solution will be sprayed to observe the colour changes.
2) *Sulphate Resistence Test:* In sulphate resistence test cube specimens of dimension (10 x 10 x 10) cm are to be casted. The concrete specimens are to be water cured for 3 days and then it will be introduced into magnesium sulphate solution and cured for another 56 days. The weight loss and changes in strength are to be noted and compared with that of specimens that are water cured. This will be conducted at the end of 56 days.
3) *Carbonation Test:* Concrete Carbonation is tested with the straightforward use of a chemical indicator; the most commonly used indicator is a solution of phenolphthalein in alcohol and/or water. The cylinder specimen of (12x20) cm will be casted and split into halves in longitudinal direction using UTM. The broken face is sprayed with a solution of phenolphthalein diluted in alcohol. The uncoloured area will indicate the carbonated region.

E. Load Deflection Test

The beam specimen is casting and placing on the loading frame apparatus to measure the deflection characteristics of the beam. The flexural behavior of under reinforced RCC beams were studied under two-point loading at 28th day.

The experimental set up consists of a loading frame with a maximum load capacity of 100T equipped with a data acquisition system. The specimen can be mounted into the equipment for any specified support and loading conditions. A calibrated load cell with a maximum load capacity of 200 KN controls the loading in a loading frame. The data acquisition unit records the load and corresponding displacement at mid span. The downward displacement is measured using a linear variable displacement transducer (LVDT) placed at mid span at bottom of the beam specimens.

The dimensions of the beam were 200mm wide, 300mm deep and 1500mm length. High yield strength deformed bars of 16mm diameter and 12mm diameter were used as tension reinforcement and hanger bars respectively. Two-legged stirrups of8mm diameter were provided at 140 mm center to center distance as shear reinforcement.

V. RESULTS AND DISCUSSION

The results obtained are,

A. Partial Replacement of Cement with Metakolin

Partial replacement of cement with metkaolin in varying percentages like 5%, 10%, 15% and 20%.Compressive strength, flexural strength and split tensile strength is shown in Fig. 1, Fig. 2 and Fig. 3.

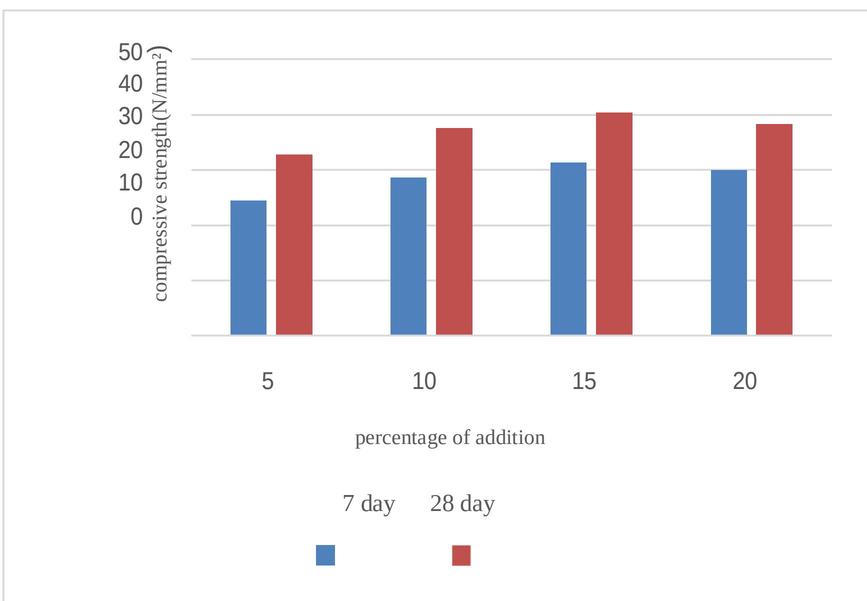

Fig. 1 Compressive strength with percentage of addition

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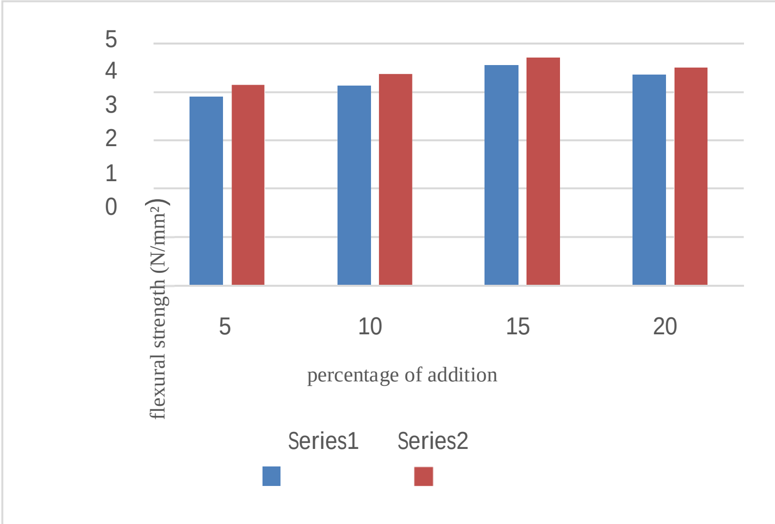


Fig. 5 Flexural strength with percentage of addition

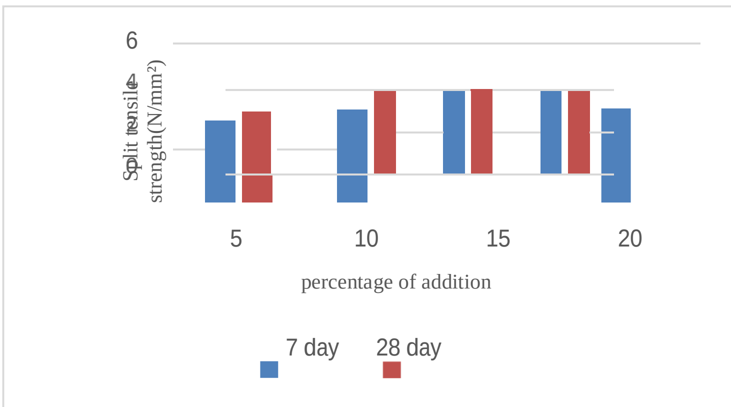


Fig. 3 Split tensile strength with percentage of addition

B. Nylon Fiber And Sisal Fiber Addition

Nylon and sisal fiber is added to the partially replaced concrete in varying percentages of 0.5%, 1% and 1.5%. Compressive strength, flexural strength and split tensile strength results are shown in Fig. 4, Fig.5, Fig.6, Fig. 7, Fig 8 and Fig 9.

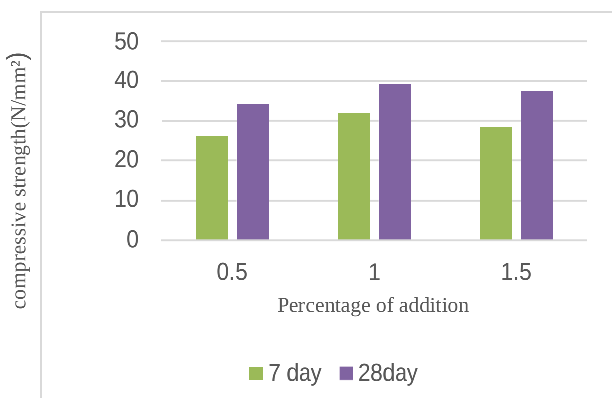


Fig. 4 Compressive strength with percentage of nylon addition

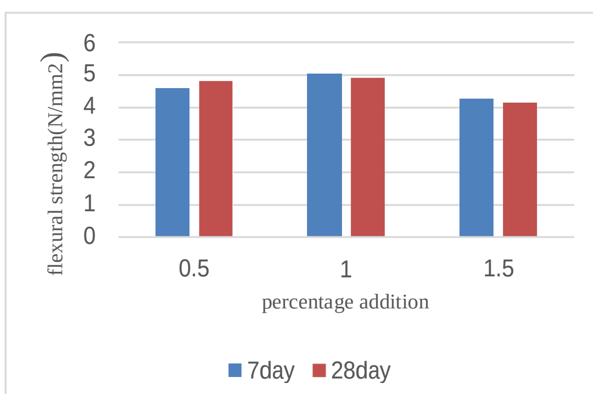


Fig. 5 Flexural strength with percentage of nylon addition

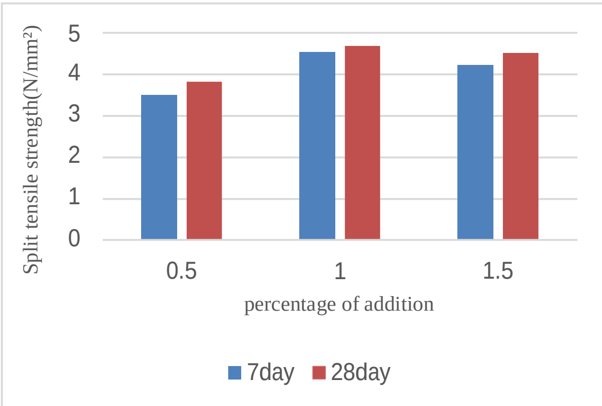


Fig. 6 Split tensile strength with percentage of nylon addition

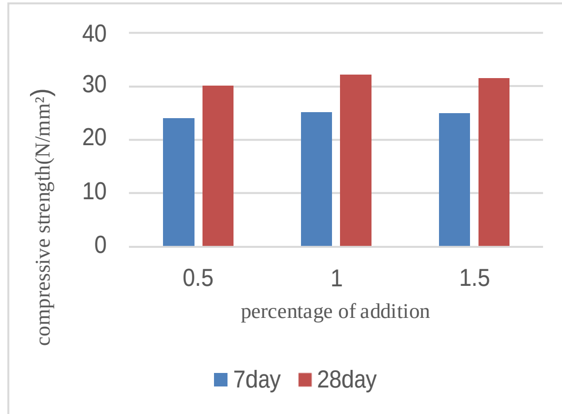


Fig. 7 Compressive strength with percentage of sisal addition

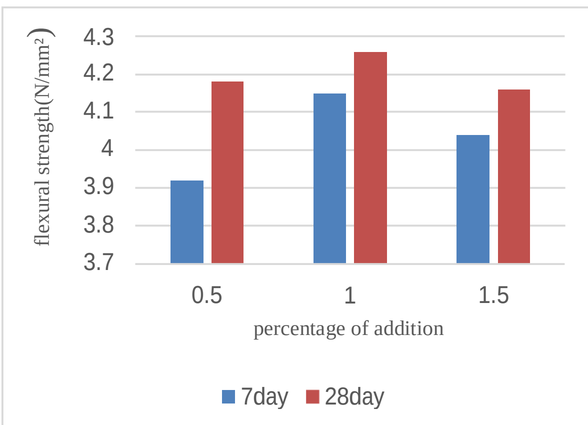


Fig. 8 Flexural strength with percentage of sisal addition

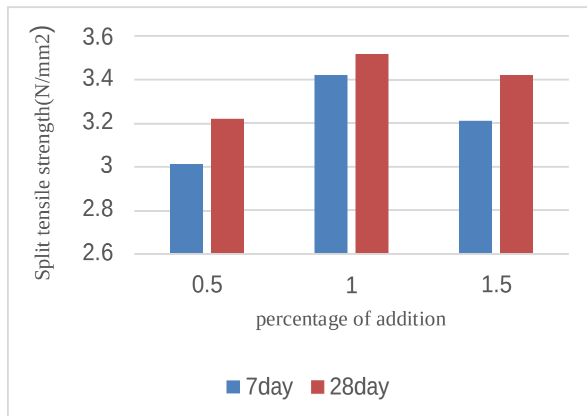


Fig. 9 Split tensile strength with percentage of sisal addition

C. Durbility

Carbonation results is shown in Fig. 10.

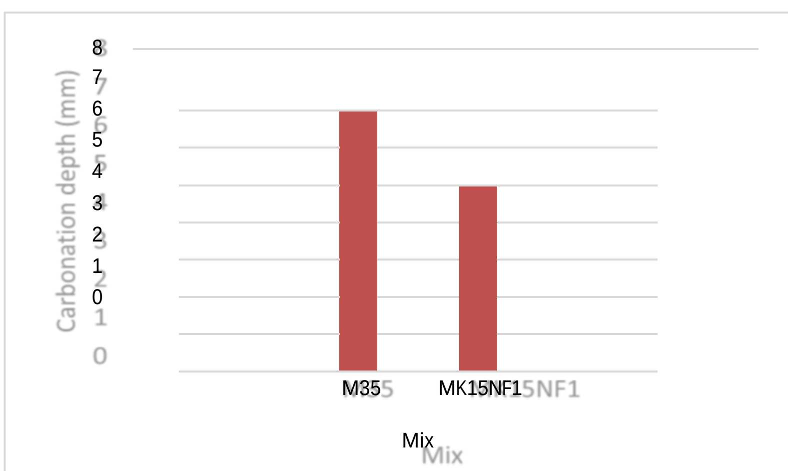


Fig. 10 Carbonation depth

The carbonation depth for the mix which having 1 % fiber is less than that of the mix having 0% fiber content. The decrease in carbonation depth in metakaolin concrete is due to pozzolonic activity.
After sulphate resistence tests, Fig.11 and Fig. 12 shows variation in strength and mass.

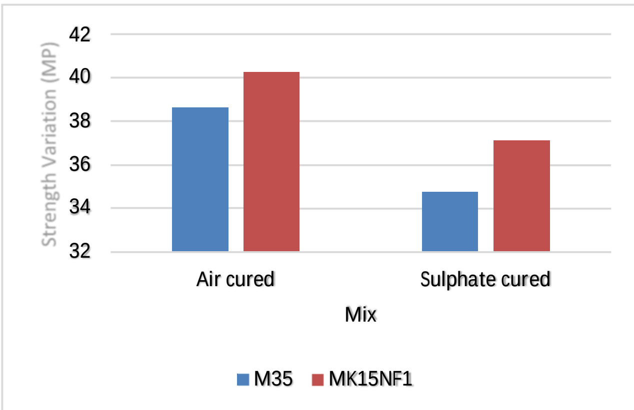


Fig.11 Variation in compressive strength

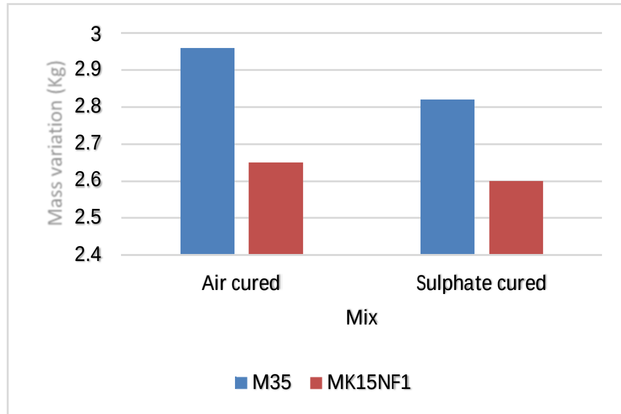


Fig 12 Changes in mass of different specimens

Bulk diffusion results is shown in table 1

Table 1 Depth of penetration of chloride ions

Mix	Depth of penetration (mm)	Diffusion coefficient ($10^{-12}m^2/s$)
M35	15	2.91
MK15NF1	4	0.83

Based on the result it was analyzed that the control mix is in the range of average permeability based on concrete society recommendations, that is in the range of (1 to 5) x 10^{-12} m^2/s. The partially replaced fiber concrete mix is in the range of low permeability that is less than $1x10^{-12}$.

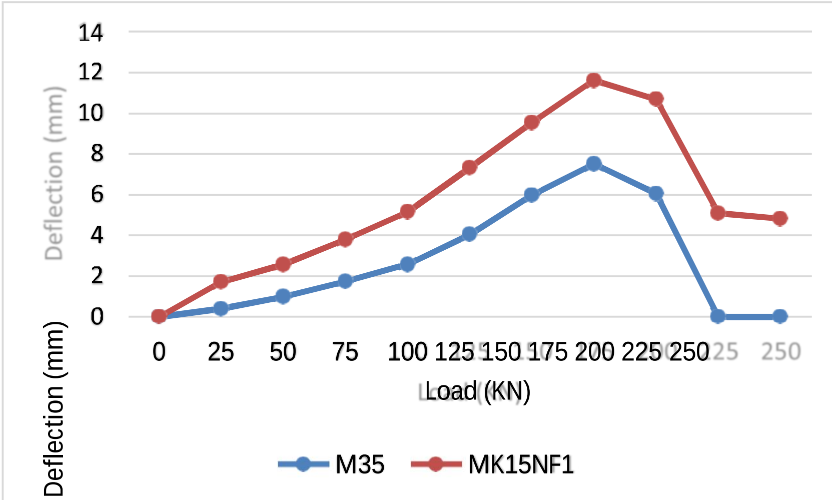
D. Load Deflection Tests

The beam specimens of 1500 x 200 x 300 mm were subjected for load deflection testing. 28 days cured specimens were given load to study its behaviour. The ultimate load and deflection of control beam and fiber reinforced concrete beams were tested.
The ultimate load and deflection of control beam and fiber reinforced concrete beams were shown in table 2 and results obtained from load deflection test were shown in Fig.13.

Table 2 Ultimate load and deflection of control and optimum specimen

MIX	Specimen Ultimate load (KN)	Maximum deflection (mm)
M35	175	7.51
MK15NF1	225	5.09

The ultimate load obtained for the concrete containing 15 % metakaolin and 1% fiber (MK15NF1) shows higher strength and less deflection than ordinary concrete mix (M35). The Fig 13 shows the load deflection behavior. For crack pattern study the specimen of M35 mix were compared with MK15NF1mix specimens. The crack developed on specimens after two point loading is described in this section. In all specimens the first crack developed is due to the flexural failure and the complete failure of specimen is due to shear.



VI. CONCLUSIONS

From the results 15% is obtained as optimum percentage of metakaolin for partial replacement of cement .Based on this partially replaced concrete nylon and sisal fiber is added sepertely on concrete mix and casted. For both fiber 1% is obtained as optimum percentage. On comparing nylon and sisal fiber added concrete,nylon fiber added mix has more strength. From the durability study the sulphate attack and chloride attack, which does not affect the strength of concrete and the optimum mix is more durable than the control mix.

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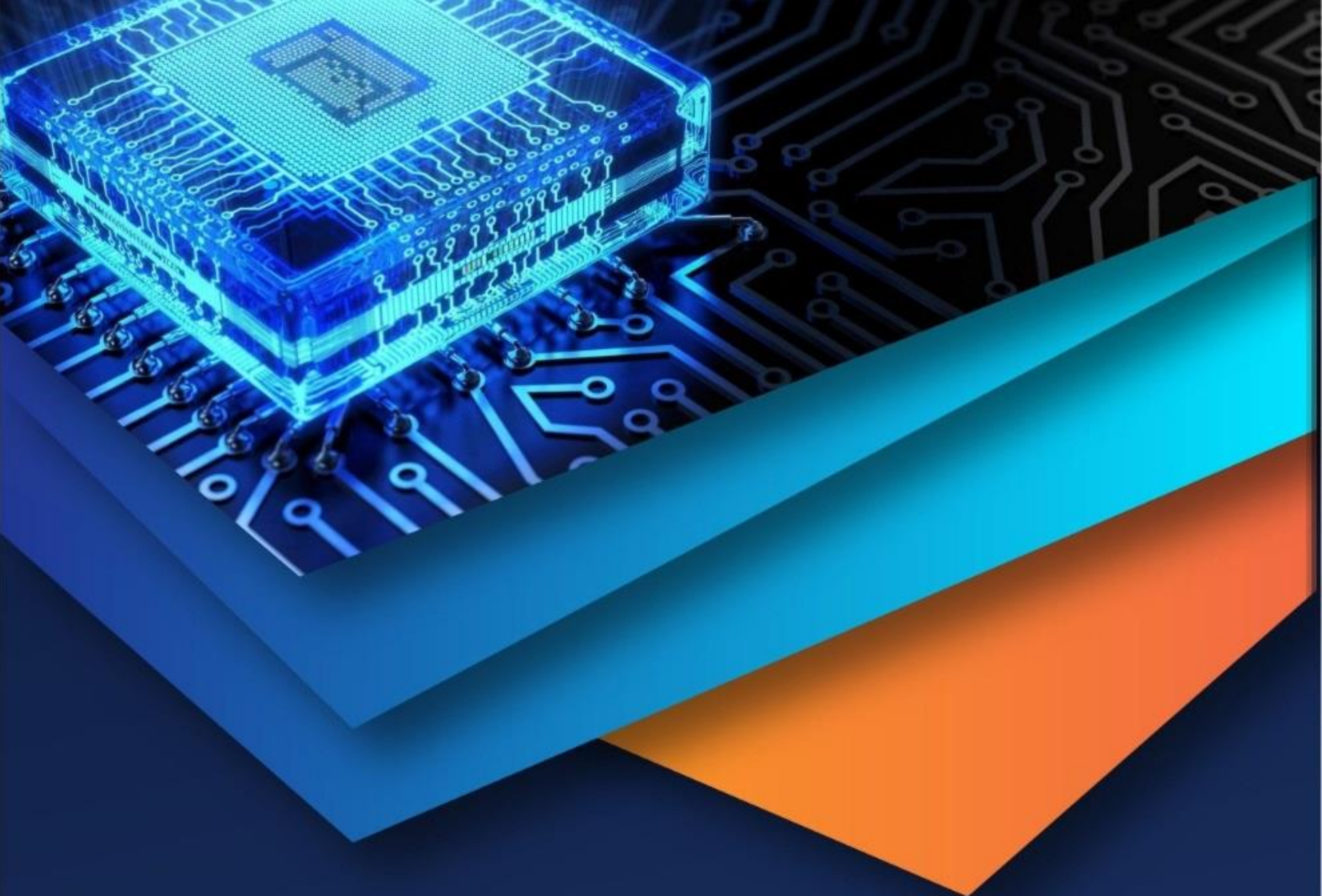

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