A Study on Partial Replacement of Cement with Metakaolin and Fine Aggregate with Waste Foundry Sand

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Abstract: **Due to constant sand mining, the natural sand is depleting at an alarming rate. So, there is a need to find alternative to natural sand.The aim of the present study is to evaluate the effect of replacing cement with metakaolin and fine aggregate with waste foundry sand. For this study M25 grade concrete is prepared and is evaluated for fresh concrete properties and hardened concrete properties like compressive, split tensile, flexural strength and modulus of elasticity. Ordinary Portland cement is replaced with metakaolin keeping10% constant, while the fine aggregate is replaced with waste foundry sand at 0, 10, 20, 30 and 40% by weight. The compressive, split tensile and flexural strength properties are compared among all the mixes at periods of 7, 28 and 56 days. The results show that the use of metakaolin and waste foundry sand improves the mechanical properties of concrete. The optimum results were observed at 10% and 30% replacements of metakaolin and waste foundry sand respectively. The increase in compressive strength at 28 and 56 days was found to be 29% and 28.9%, which is 40.1MPa and 41MPa when compared to the nominal mix which is 31MPa and 31.8MPa respectively.**

Key words: Metakaolin, Waste foundry sand, workability, Modulus of elasticity and strength.

I INTRODUCTION

Concrete is the most widely used man-made construction material in the world. The consumption of all type of aggregates has been increasing in recent years. Artificially manufactured aggregates are more expensive to produce and the other factor to be considered is the continuous extraction of natural aggregates which causes serious environmental problems. Recycling and utilization of industrial by-products and waste materials has become an attractive proposition to disposal. The utilization of such materials in concrete not only makes it economical, but also helps in reducing disposal concerns. One such industrial waste material is Waste Foundry Sand (WFS). The Indian Metal Casting (Foundry Industry) is well established and producing 10 Million MT (2015) of various grades of Castings. The various types of castings produced are ferrous, non ferrous, Aluminum Alloy, graded cast iron, ductile iron, Steel etc. According to the 49th Census of World Casting Production, Indian Foundry Industry is the 3rd largest metal casting producer in the world. There are approximately 5,000 foundry units in India. The majority (nearly 90%) of the foundry units in India falls under the category of micro, small and medium scale industries (Foundry informatics centre). Metakaolin is in widespread use all over the world in the concrete industry. The advantages of Metakaolin not only have many concrete performance benefits, both in mechanical and durability properties, but also the environmental benefits. While the production of Portland cement is associated with high carbon dioxide emissions. Metakaolin is a dehydroxylated form of the clay mineral kaolinite. Metakaolin can be produced by primary and secondary sources containing kaolinite are high purity kaolin deposits, kaolinite deposits or tropical soils of lower purity, paper sludge waste which contains kaolinite, oil sand tailings contains kaolinite. Metakaolin usage helps in developing high performance and high early strength in concrete.

II LITERATURE REVIEW

Amritpal Kaur, Rajwinder Singh Bansal studied the strength characteristics by using metakaolin and marble powder as partial replacement of cement. Grade of concrete: M30. The replacement of cement has been done at 0%,3%,5%,9%,12%,13% with Metakaolin (MK) and 0%,10%(constant) with Marble Powder (MP). Compressive as well as tensile strength of concrete made with MK-MP has been compared with conventional concrete. The optimum percentage for replacement of cement with Metakaolin and Marble powder was 9% and 10%.

Vijay Shankar, Suji Studied the properties of HPC which were determined by using Metakaolin as partial cement replacement and Quarry dust as partial fine aggregate replacement. Grade of concrete: M40. The Percentage of replacements are 0, 2.5,5,7.5,10,12.5 & 15 % for Metakaolin and 0,10,20,30,&40% for quarry dust.The maximum compressive as well as split tensile strengths were obtained at replacements, 10% of cement with Metakaolin and 30% of sand with Quarry Dust with 3% Super Plasticizers.

Ravitheja, Gopala Krishna Sastry studied the strength properties of concrete with different percentages of replacement of sand by used foundry sand and silica fume. Grade of concrete: M25. The replacement percentages are 0%, 10%, 20%, 30%, 40%, and 50%. Thus obtained optimum percentage of used foundry is taken as constant and cement is replaced with silica fume in the percentages of 5%, 7.5%, 10% and fly ash by 10%, 15%, and 20%. When 40% of fine aggregate is replaced by used foundry sand the strength observed was 38.70 MPa. Replacement of 40% used foundry sand with silica fume showed better performance than with fly ash. The maximum increase in strengths was observed when 40% used foundry sand with 10% silica fume is used and the strength obtained was 42.96 Mpa.

III. EXPERIMENTAL DETAILS

The experiments were carried out at 10% replacement of cement by metakaolin and 0, 10, 20, 30 and 40% replacements of fine aggregate by waste foundry sand. The fresh concrete properties were studied and hardened properties of concrete were carried out at 7, 28 and 56 days.

A. Properties of the materials

Cement: Ordinary Portland Cement (OPC) of 53 Grade from a single lot was used throughout the experimental investigation. The specific gravity of cement obtained is 3.15.

Fine aggregate: The sand obtained for the investigation is from nearby river course. The sand obtained from quarry was sieved through all sieves. The specific gravity of fine aggregate is 2.6 and fineness modulus is 2.72.

Coarse aggregate: The coarse aggregate used in this investigation are obtained from local crushing unit. The size of aggregate used in this investigation is 20mm. The specific gravity of fine aggregate is 2.75 and fineness modulus is 7.31.

Water: The water available in the JNTU College of engineering has been used for this experimental investigation.

Metakaolin: Metakaolin used in this experimental investigation was obtained from the supplier ASTRRA Chemicals, Chennai. The specific gravity is 2.6.

Waste foundry sand: Waste foundry sand used in this experimental investigation was obtained from Sri Bhavani castings, Kakinada. The specific gravity is 2.17.

Super plasticizer: The super plasticizer used in this experimental investigation is Conplast SP430. The specific gravity is 1.20

IV. SPECIMEN DETAILS

Cube specimen of size 150 mm x 150mm x 150mm, Cylinder specimen of 150 mm diameter and 300 mm height and beam of size 700 mm x 150 mm x 150 mm were casted to study the hardened properties of concrete such as compressive strength, split tensile strength, flexural strength and modulus of elasticity.

Mix notations

- N- Nominal mix
- M- 10% metakaolin and 0% waste foundry sand
- A- 10% metakaolin and 10% waste foundry sand
- B- 10% metakaolin and 20% waste foundry sand
- C- 10% metakaolin and 30% waste foundry sand
- D- 10% metakaolin and 40% waste foundry sand
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V. MIX PROPORTIONS

M25 grade of concrete is cast. The design is based on IS 10262-2009. The quantities obtained from this design. The quantities were tabulated in table 1.

Table 1: Details of mix proportion

S.No	Material	Units	Material quantities					
			N	M	A	B	C	D
1.	Cement	Kg/m^3	356.4	320.8	320.8	320.8	320.8	320.8
2.	Metakaolin	Kg/m^3	-	35.6	35.6	35.6	35.6	35.6
4.	Fine aggregate	Kg/m^3	704.2	704.2	633.8	563.3	492.9	422.5
5.	Waste foundry sand	Kg/m^3	--	--	70.4	140.8	211.2	281.7
6.	Coarse aggregate	Kg/m^3	1272.8	1272.8	1272.8	1272.8	1272.8	1272.8
7.	Water	lit/m^3	153.26.	153.26	153.26	153.26	153.26	153.26
8	Super Plasticizer	lit/m^3	2.5	2.5	2.5	2.5	2.5	2.5

VI. TEST RESULTS

Fresh concrete test results and graphs

The fresh concrete properties were tabulated in table 2 and the slump cone test results were shown in the figure 1.

Table 2 Slump values

S.No	Mix Id.	Slump (mm)
1	N	70
2	M	61
3	A	56
4	B	47
5	C	40
6	D	31

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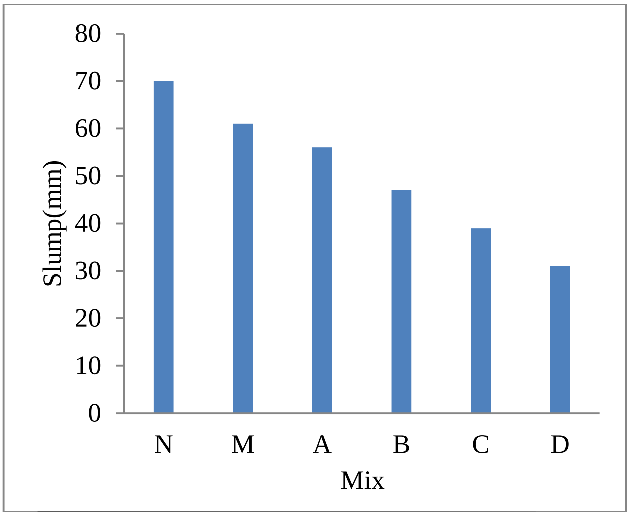

Fig-1 Slump vs. Mix

- The Slump values decreased with respect to the replacement levels, more the replacement of foundry sand, less is the slump observed.

Hardened concrete test results and graphs

Table 3: Hardened concrete properties (MPa)

Mix Id.	Compressive strength			Split tensile strength			Flexural strength		
	7d	28d	56d	7d	28d	56d	7d	28d	56d
N	20.5	31	31.8	1.88	2.66	2.80	4.26	5.73	5.98
M	24.6	36.7	38	1.95	2.9	3.04	4.77	6.36	6.50
A	23.6	37.4	38.33	1.99	3.06	3.18	4.95	6.76	6.91
B	24.9	38.2	39.1	2.01	3.28	3.44	5.20	6.82	7.12
C	27.6	40.1	41	2.24	3.42	3.53	5.49	7.20	7.64
D	23	36	36.9	1.89	2.78	2.93	4.81	6.30	6.44

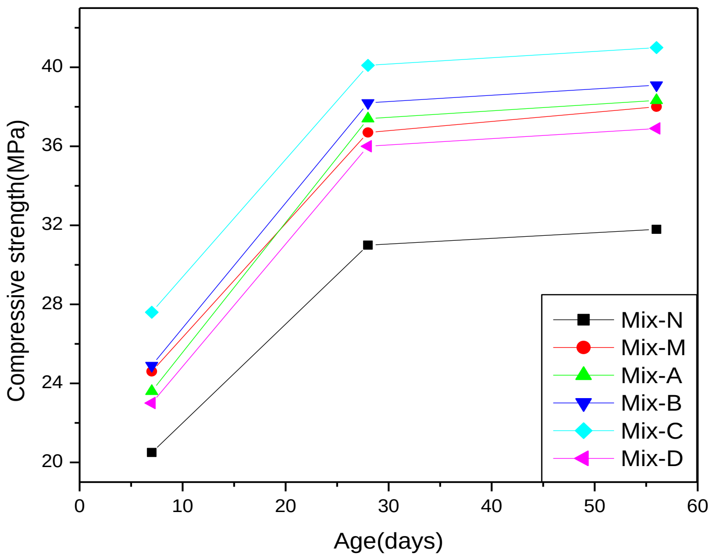

Fig 2: Compressive strength vs. Age

- Figure-2 indicates the comparison between compressive strengths of Mix N, M, A, B, C, D. It is observed that the compressive strengths of Mix-M at 7 days, 28 days showed an increment of 18%, 19% than Mix-N.
- The 7days strength of Mix-A showed 15% increment than Mix-N, where as it has shown a decrement of 4% than Mix-M.
- At 7 days Mix-C showed an increment of 34% than mix-N and 12% increment than Mix-M.
- Among the four mixes A, B, C, D Mix-C has attained highest strength and Mix-D has recorded least strength.

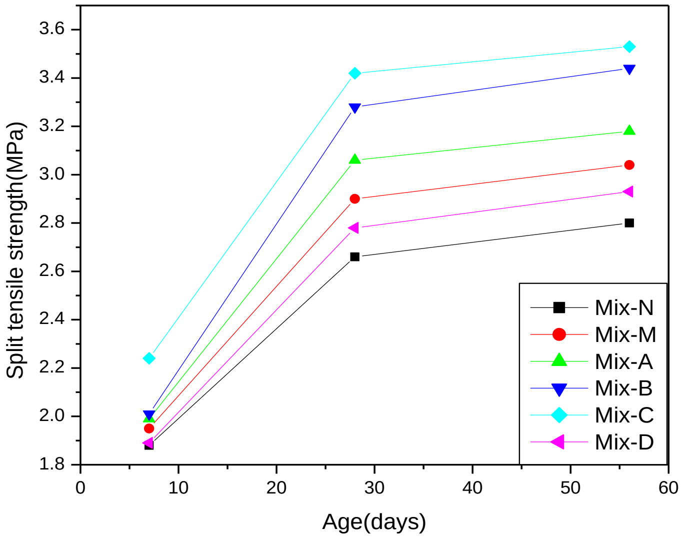

Fig 3: Split tensile strength vs. Age

- Figure-3 indicates the comparison between split tensile strengths of Mix N, M, A, B, C, D.
- Among the four mixes A, B, C, D Mix-C attained highest strength and the strengths of Mix-D showed decrement than Mix-M.
- At 7 days Mix-C has shown an increment of 19% than Mix-N and 14% increment than Mix-M.
- It is observed that the strengths of Mix-M at 7 days, 28 days showed an increment of 3.7%, 9% than Mix-N.

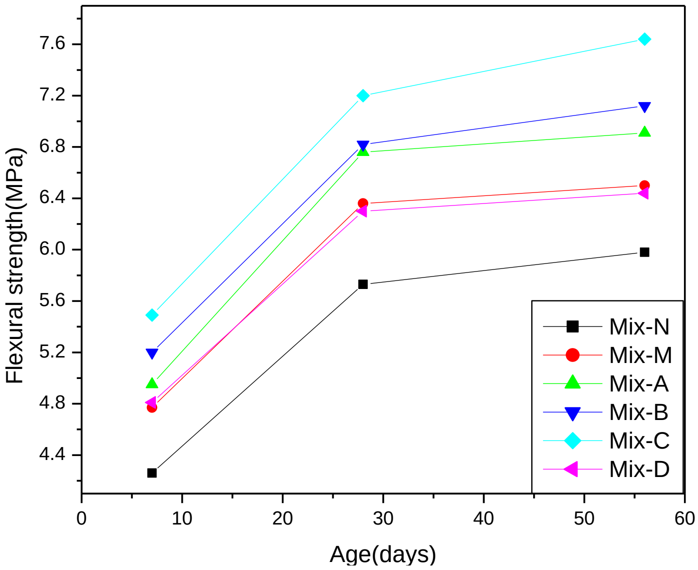

Fig 4: Flexural Strength vs. Age

- Figure-4 indicates the comparison between flexural strengths of Mix-N, M, A, B, C, D at a period of 7, 28 and 56 days.
- It was observed that the %Variation of strength for Mixes-M, A, B, C, D at 28 days are less than that of 7 days
- At 7 days Mix-C showed an increment of 28.8% than mix-N and 15% increment than Mix-M.
- At 28 days Mix-D showed 0.9% decrement of strength than Mix-M.

Deflections obtained from corresponding loads were tabulated in table 4.

Table 4 Stress-Strain values for Mix-N specimen

Load (kN)	Deflection (mm)	Stress (MPa)	Strain
0	0	0	0
40	0.015	2.263596	0.0001
80	0.029	4.527191	0.000193
120	0.045	6.790787	0.0003
160	0.061	9.054383	0.000407
200	0.078	11.31798	0.00052
240	0.094	13.58157	0.000627
280	0.11	15.84517	0.000733
320	0.127	18.10877	0.000847
360	0.145	20.37236	0.000967
400	0.163	22.63596	0.001087
440	0.184	24.89955	0.001227
460	0.202	26.03135	0.001347
480	0.22	27.16315	0.001467
500	0.248	28.29495	0.001653
510	0.272	28.86085	0.001813
520	0.312	29.42674	0.00208
490	0.348	28.29495	0.00232
485	0.42	27.4461	0.0028

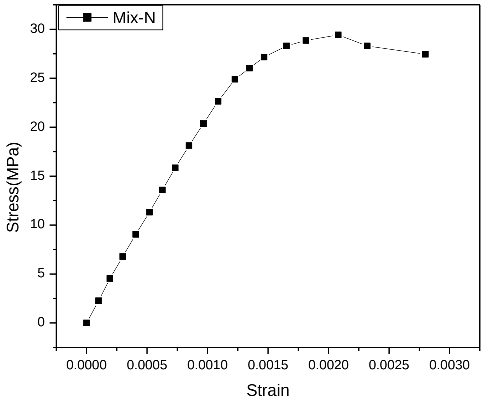

Fig 5 Stress vs. Strain

- Figure-5 indicates the stress-strain curve of Mix-N specimen tested at the age of 28days.
- The ultimate strength of Mix-N cylinder obtained is 520kN.
- The maximum strain observed at peak stress (29.42MPa) is 0.00268.
- Secant modulus calculated is 20 GPa.

Deflections obtained from corresponding loads were tabulated in table 5

Table 5 Stress-Strain values for Mix-C specimen

Load (kN)	Deflection (mm)	Stress(MPa)	Strain
0	0	0	0
40	0.008	2.264685067	5.33333E-05
80	0.018	4.529370134	0.00012
120	0.028	6.794055202	0.000186667
160	0.039	9.058740269	0.00026
200	0.05	11.32342534	0.000333333
240	0.06	13.5881104	0.0004
280	0.07	15.85279547	0.000466667
320	0.08	18.11748054	0.000533333
360	0.092	20.38216561	0.000613333
400	0.103	22.64685067	0.000686667
440	0.114	24.91153574	0.00076
460	0.12	26.04387827	0.0008
480	0.129	27.17622081	0.00086
500	0.137	28.30856334	0.000913333
520	0.148	29.44090587	0.000986667
540	0.16	30.57324841	0.001066667
560	0.176	31.70559094	0.001173333
580	0.194	32.83793347	0.00128
600	0.214	33.97027601	0.0014

620	0.236	35.10261854	0.001573333
640	0.286	36.23496108	0.001906667
645	0.312	36.51804671	0.00208
635	0.332	35.95187544	0.002213333
630	0.341	35.66878981	0.002273333
600	0.384	33.97027601	0.00256
580	0.4	32.83793347	0.002666667

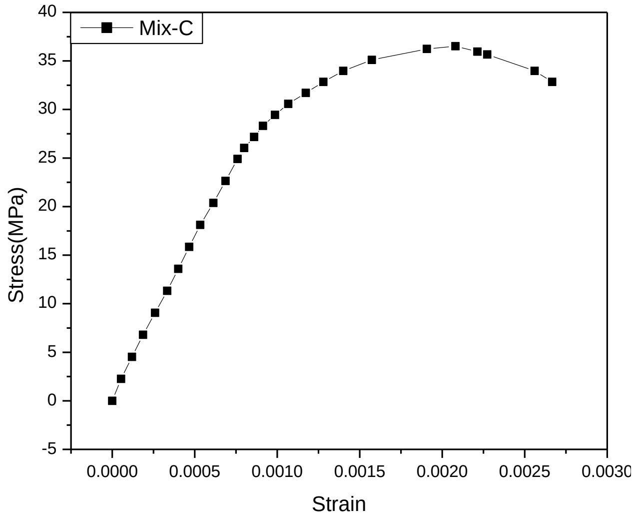

Fig 6 Stress vs. Strain

- Figure-6 indicates the stress-strain curve of Mix-C specimen tested at the age of 28days.
- The ultimate strength of Mix-C cylinder obtained is 645kN.
- The maximum strain observed at peak stress (36.51 MPa) is 0.00208.
- Secant modulus calculated is 29.3 GPa.

VII. CONCLUSIONS

- From the sieve analysis, it was found that waste foundry sand has finer material than fine aggregate.
- As Metakaolin is a very fine material the finishing of surfaces of the specimens were observed evenly smooth.
- It was observed that as the percentage of foundry sand increases, the workability decreases because of the presence of finer particles.
- Due to the addition of 10% metakaolin, high early strengths were observed in Mix- A, B, and C.
- Mix-D which is 40% replacement of fine aggregate by waste foundry sand, showed decrement in strengths than Mix-M.
- It was observed that there is an increment in compressive strength of 29% in Mix C than compared to Mix N and 9% increment than Mix-M.
- It was observed that there is an increment in split tensile strength of 28% in Mix C than compared to Mix N and 18% increment than Mix-M.
- It was also observed that there is an increment in flexural strength of 25.6% in Mix C than compared to Mix N and 13% increment than Mix-M.
- It was found that Mix C is the optimum mix than compared to all other mixes for all the strengths.
- From the stress-strain curve the modulus of elasticity for Mix-N obtained is 20GPa, and for Mix-C obtained is 29.3GPa.
- From the above, it is concluded that, the maximum replacement of foundry sand can be up to 30% in fine aggregate by keeping metakaolin at constant rate of 10%.

VIII. REFERENCES

[1] American Foundry men's Society. Alternative utilization of foundry waste sand. Final Report (Phase I) prepared by American Foundry men's Society Inc. for Illinois Department of Commerce and Community Affairs, Des Plaines, Illinois, 1991.

[2] Foundry Industry Recycling Starts Today (FIRST). Foundry Sand Facts for Civil Engineers. Federal Highway Administration Environmental Protection Agency Washington, DC; 2004.

[3] K.A.Gruber, Terry Ramlochan, Andrea Boddy, R.D.Hooton, M.D.A.Thomas, Increasing Concrete durability with high reactivity metakaolin, Cement & Concrete Composites, Vol. 23, 2001, 479-484.

[4] Naik, T.R.; Kraus, N. Rudolph; Chun, Yoon- moon; Ramme, W. Bruce; and SiddiqueRafat, May-June2004.Precast Concrete Products Using Industrial By-Products. ACI Materials Journal. 101, No. 3,pp 199- 206.

[5] Saveria Monosi, Daniela Sani and Francesca Tittarelli, (2010) "Used Foundry Sand in Cement Mortars and Concrete Production", The Open Waste Management Journal, 2010, 3, 18-25, Italy.

[6] Shreeti S. Mavinkurve, Prabir C. Basu and Vijay R. Kulkarni, High Performance concrete using high reactivity metakaolin, The Indian Concrete Journal, May 2003, 1077-1085

[7] Tarun R. Naik and Rudolph N. Kraus "The role of flowable slurry in sustainable developments in civil Engineering" Presentation and Publication at the ASCE Conference on Materials and Construction – Exploring the Connection, May 10-12, 1999, Cincinnati, Ohio. Report No. CBU- 1999-01 REP-358 January 1999.

[8] Tikalsky, J. Paul, Smith, Earl and Regan, W. Raymond, December 1998. Proportioning Spent Casting Sand In Controlled Low-Strength Materials. ACI Material Journal, V.95, No.6, Pp 740 746.

[9] Wild, S., J.M. Khatib, and A. Jones, ―Relative strength, pozzolanic activity and cement hydration in super plasticized metakaolin concrete, Cement and Concrete Research, vol. 26, pp. 1537-1544, Oct. 1996.

[10] Zhang, M. H., and Malhotra, V. M., "Characteristics of a Thermally Activated Alumino Silicate Pozzolanic Material and Its Use in Concrete, Cement & Concrete Research, V. 25, No. 8, 1995, pp. 1713-1725.

[11] Indian Standard code IS 10262-2009