https://dx.doi.org/10.24001/ijaems.3.6.12 ISSN: 2454-1311

The Effect of addition of Spent Catalyst and Steel fibres on the strength properties of concrete

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Abstract - *Large quantities of CO_2 are released into the atmosphere in the production of cement. The CO_2 production increases the hazard of global warming which has forced the researchers to find materials which can partially or fully replace cement. Industrial by-products like fly ash, Ground Granulated Blast Furnace Slag, Silica fume, Rice husk Ash are tried as partial cement replacement materials by virtue of their possessing pozzalonic action when they come in contact with water in concrete. Hence these industrial by-products are termed as Supplementary Cementitious Materials [SCM].Spent catalyst is one such industrial by-product of Oman from Petroleum Refineries produced from the cracking of petroleum to reduce the sulphur content and to enhance the combustion properties of the oil. To improve the tensile strength of concrete, discontinuous discrete fibres are added to cement matrix and are termed as Fiber Reinforced Concrete. In this project an attempt has been taken up to carry out an experimental investigation to study the effect of addition of spent catalyst and steel fibers on the characteristic strength properties of concrete. 15% by weight cement is replaced by spent catalyst as partial replacement of cement and steel fibers of aspect ratio 60 are added at 0.2%, 0.3% and 0.4% by volume of concrete. C30 grade reference concrete mix was cast for strength comparison. 150 mm x 150 mm x 150mm size cube moulds, 150 mm diameter and 300mm height cylindrical specimens and 500 mm x 100 mm x 100mm beam specimens were cast and tested to find the characteristic strength properties of all the concrete mixes cast. The experimental results show that the concrete mix M3 containing 15% partial replacement of cement by spent catalyst and 0.20% steel fibers with an aspect ratio of 60 shows maximum compressive stress of 42.05N/mm^2, maximum split tensile strength of 5.25 N/mm^2 and maximum flexural strength of values of 4.20 N/mm^2. The test results also show that the concrete mix M5 containing 15% partial replacement of cement by spent catalyst and 0.40% steel fibers with an aspect ratio of 60 shows minimum compressive stress of 38.10 N/mm^2, minimum split tensile strength of 4.76 N/mm^2 and minimum flexural strength of 3.80 N/mm^2. Finally the study shows that 15% partial replacement of cement by spent catalyst with addition of 0.20% steel fibers with an aspect ratio of 60 produce satisfactory results.*

Keywords- **S*pent catalyst, Steel fiber, Concrete, strength, Steel fiber, Cementitious materials.***

I. INTRODUCTION

1.1 Supplementary Cementitious Materials

Fly ash, Ground Granulated Blast Furnace Slag (GGBS), silica fume, Rice bush ash and Natural pozzolonic are Supplementary cementitious Material. Supplementary cementitious materials are waste materials that are produced from various. Many efforts were made to use the Supplementary cementitious Materials as cement replacement or partial cement replacement materials in order to minimize its disposal and reduce the pollution generated by cement production process.

Fly ash: The fly ash is an industrial by-product obtained by burning coal in thermal power stations. Moreover, the fly ash is non-combustible particles that are collected from the flue gases. Furthermore, proper percentage of fly ash to be implemented in concrete is determined based on the performance required, sources and composition of fly ash. The Fly ash of F class is produced from bituminous coal or burning anthracite and it generally has low content of calcium. The class-C fly ash is formed by burning subbituminous coal and it has pozzalonic properties (Samara, M., 2013).

Ground Granulated Blast Furnace Slag: GGBS is by-product material and it is generated when the iron ore converted to pig iron. Immediately, the liquid slag is cooled in water and form granules. The obtained granules are ground to achieve smaller particles.

Silica fume: This material is a by-product of ferrosilicon metal or silicon manufacture (in other words, clay or shale heated and ground after being cooled rabidly) and it is a highly reactive pozzalonic substance. The arc furnaces produce flue gases and the silica fume is collected. The silica fume particles size is very small and the average size of cement grains is about 100 times

https://dx.doi.org/10.24001/ijaems.3.6.12 ISSN: 2454-1311

bigger than silica fume particles size. This material is available in form of water-slurry or dens powder. ASTM C 1240 is the standard specification for the silica fume and it is added at the percentages from 5 to 12 by mass of binder for mixture where high strength is needed. Special procedure is applied when the silica fume is handled, cured and placed due to its extreme fitness.

Rice hush ash: The ash collected from controlled rice husks burning after separation of rice grains. The Rice hush ash is considered as a very effective SCM. This material has great surface area and contains high quantity of silica soluble which is in condition of alkaline. 15 to 20 percent of Rice hush ash is silica, 50 percent cellulose and 25 to 30 percent of lignin. A 30 percent of cement can be replaced by Rice hush ash due to high silica content that material has. This replacement will enhance the mechanical properties of concrete. Partial replacement of cement with Rice hush ash in concrete will generate C-S-H gel and that helps in strengthen the bound between the aggregate (National Ready Mixed Concrete Association, 2000).

Spent catalyst: This material is a by-product from oil refineries obtained by adding the fresh catalysts to oil cracking in order to minimize the amounts of sulphur content and to develop the oil properties of combustion. Oman has two sources of spent catalyst, one is Mina Al-Fahal Refinery and the other one is from Sohar refinery (Al-Jabri, K. et al., 2013). Supplementary cementitious materials (SCM) like spent catalyst when they come in contact with water will react with the calcium hydroxide of cement and produce C-S-H gel. By this process with the addition of SCM, the microstructure of the cement paste will be improved which enhance the strength properties of concrete.

Fibres:

Many properties of concrete can be enhanced by addition of deferent types of fibers in concrete mixture. There are many types of fibres such as Steel fibres, Asbestos fibres, Organic fibres, carbon fibres, Polypropylene fibres and glass fibres.

Steel fibres: The concrete physical properties, performance under different types of loads and performance under vibration are improved by addition of steel fibres into the concrete mixture. The concrete that is reinforced by steel fibres preforms as a composite material and its reinforcement is provided in all directions. Even when the crack appears, the FRC is able to carry the loads because of the high ductility that concrete acquired. The addition of the steel fibres improves the concrete strength, enhances the edge protection and develops the control of crack and shrinkage. There are various types of steel fibres such as Crimpt, hooked-end, straight, etc. (Neeraja, 2013)

II. LITERATURE REVIEW

Konapure & Dasari, 2015. An experimental work done to investigate the effect of addition of Silica Fume and Steel Fiber on the flexural strength and compressive strength of concrete. The mixed proportion used in this research is 1:1.97:2.75 while the water binder ratio is 0.41. The prepared mixture contained hook-end steel fiber with volume fraction of 1 percent and the selected aspect ratio of the steel fibres is 71. The replacement percentage of cement by silica fume is 5 percent by weight replacement. A chemical admixture which is superplastisizer was added to the mixture to get the desired workability. The relationship between compressive strength, workability and flexural tensile strength of concrete was represented graphically and mathematically. The results achieved from the prepared specimens were compared with results achieved from the control concrete specimens.

Sukumar & John, 2015. Fibres are used in concrete to provide cracking resistance besides increasing its strength. In this research, steel fibres are added to concrete to investigate its influence on concrete. Many researchers concluded that the compressive strength of the concrete containing steel fibres is much more than the compressive strength containing polypropylene and glass fibers. The volume fraction Percentage of hooked steel fibres varied from 0 percent to 0.38 percent and the diameter of steel fibres used is 0.75mm. For this experimental work, concrete cubes and beams were cast to test the compressive and flexural strength of concrete. It was found that the steel fibres enhance the strength properties of concrete.

Al-Jabri, K. et al., 2014. In this paper, the authors defined the spent catalysts as materials produced from the cracks of petroleum in oil refineries when fresh catalyst is added to minimize the sulphur content and to develop the oil properties of combustion. The authors mentioned that considerable quantities of spent catalysts are produced in Sohar and Mina Al-Fahal Refineries in Oman. The Spent catalyst produced in Refinery of Sohar is Zeolite catalyst while the spent catalyst produced in Mina Al-Fahal Refinery is Equilibrium catalyst. The aim of the study discussed in this paper is to investigate the effect of partial replacement of cement by spent catalyst on concrete properties. The Cement replacement percentages examined were up to 10 by cement weight and the ratios of water-to-binder are 0.5 and 0.7.

Al-Jabri, K. et al., 2013. This research was done to study the effect of addition of spent catalyst on the mortar's compressive strength. The by weight sand replacement was done with the percentages of 5, 10, 15, 20 and 25. Moreover, the by weight replacement of cement by the spent catalyst was done with the percentages of 2,4,6,8

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and 10. The water binder ratios used were 0.50, 0.55 and 0.60 while the binder to-sand ratio was one to three. The cast specimens were tested after curing periods of 7, 14, 28, 56 and 91 days. Good results were found when sand in concrete was partially replaced by Sohar refinery's spent catalyst. Minor effects on the concrete compressive strength were recorded when cement was partially replaced by spent catalyst produced by Sohar and Mina Al-Fahal. The Leachate tests showed that spent catalyst has no negative impact on the environment if used as construction material.

Neeraja, 2013. According to the previous researches, it is well known that the concrete resistance against cracking is improved by addition of steel fibres into the mixture. As a result, the fibres can enhance the tensile strength of concrete. Even if cracks appear on concrete, the steel fibres have the ability of keeping concrete components connected. After inclusion of steel fibres in the concrete mixture, the ordinary concrete is noticed to be ductile material.

III. EXPERIMENTAL INVESTIGATION

3.1 Materials Collection and properties:

The materials used to cast the concrete specimens are Cement, Steel fibres, Water, Aggregate and Spent catalyst. Cement is used to form the binder material needed for casting the concrete specimens. The cement used for this experimental work is Ordinary Portland cement (Type I) having grade of 43. The cement used was obtained from CCE material lab. The specific gravity of cement used is 3.15 and its colour is greenish gray.

Steel fibers: Hooked-end Steel Fibers with aspect ratio of 60 and having tensile strength of 1150 MPa were used in this experimental work. The dimensions and details are shown in Table.1. The zeolite Spent catalyst that was gained from Sohar Refinery of ORPIC and used for this experimental work has gray colour. Physical properties and chemical composition of Spent Catalyst presented in Table 2. The mean particles size of spent catalyst is 97 µm. This material is considered as hazardous waste thus, using safety measures while dealing with this material is mandatory.

Table.1: Steel Fibres Dimensions

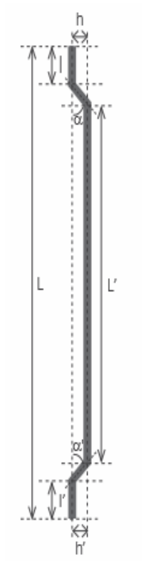
Dimensions		
Wire diameter (d)		1.00 mm (± 0.04 mm)
Fibre length (L)		60.0 mm (+2/-3 mm)
Hook length (l and l')		1 – 4
Hook depth (h and h')		1.80 mm (+1/-0 mm)
Bending angle (a and a')		45° (min. 30°)
Aspect ratio (L/d)		60
Camber of the fibre		Max. 5% of l'
Torsion angle of the fibre		< 30°
Number of fibres per kg		2600
Total fibre length per 10 kg		1575 m

Table.2: Physical properties and Chemical composition of Spent Catalyst

Typical chemical composition		Typical physical properties	
Calcium Oxide	45 %	colour	Dry grey
Silica	40%	Specific gravity	2.9
Alumina	19%	Bulk density	800 kg/m^3
Magnesia	10%	Fineness	>1100 m^2/kg

Table.3: Test Programme

Mix. No.	Cement kg	Fine aggreg-ate kg	Coarse aggreg-ate kg	Water kg	Spent catalyst kg	Steel fibres kg
Mix 1(Reference Mix)	16.166	33.50	39.40	7.6	0	0
Mix 2 (15% of Spent catalyst+ 0% of steel fibre)	13.74	33.50	39.40	7.6	2.42	0
Mix 3 (15% of Spent catalyst+ 0.2% of steel fibre)	13.74	33.50	39.40	7.6	2.42	0.644
Mix 4 (15% of Spent catalyst+ 0.3% of steel fibre)	13.74	33.50	39.40	7.6	2.42	0.966
Mix 5 (15% of Spent catalyst+ 0.4% of steel fibre)	13.74	33.50	39.40	7.6	2.42	1.23

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3.2 Testing of Specimens Cast:

The compressive strength, Split tensile strength and flexural strength of concrete specimens contained spent catalyst and steel fibres are tested and compared with the results obtained from the reference mix.

3.3 Compressive strength test:

C30 grade concrete cube specimens with dimensions of (150mm x 150mm x 150mm) were cast to conduct the compressive strength test. The cubic moulds were filled with 0%, 0.2%, 0.3% and 0.4% of steel fibres, 0% and 15% by weight replacement of cement with spent catalyst. After 24 hours from specimens casting, the cubes were demoulded and cured for 28 days. After curing, the cubes were tested under the universal testing machine having capacity of 1000kN. Three cubes were tested in each category and the average value of the three cubes was recorded (Fig.1).

3.4 Split tensile strength test:

C30 grade cylinders specimens with of dimensions (150mm diameter and 300mm height) were cast to conduct split tensile strength test. The cylinders moulds were filled with 0%, 0.2%, 0.3% and 0.4% of steel fibres, 0% and 15% by weight replacement of cement with spent catalyst. After 24 hours of casting the specimens, the cylinders were demoulded and cured from 28 days. After curing, the cylinders were tested under the universal testing machine having capacity of 1000kN. Three cylinders were tested in each category and the average value of the three cylinders was recorded (Fig.2).

3.5 Flexural strength test:

C30 grade beams specimens with of dimensions (100 mm x 100 mm x 500 mm) were cast to conduct flexural strength test. The beams moulds were filled with 0%, 0.2%, 0.3% and 0.4% of steel fibres, 0% and 15% by weight replacement of cement with spent catalyst. After 24 hours from casting the specimens, the beams were demoulded and cured for 28 days. After curing, the beams were tested under the universal testing machine having capacity off 1000kN. Two beams were tested using third point method and in each category .the average value of the two beams was recorded (Fig.3).

Fig.1: Compressive strength test

Fig.2: Split tensile strength

Fig.3: Flexure test

IV. RESULTS AND DISSCUSSION

4.1 Experimental Results:

Table 4 shows the 28 days characteristic compressive strength test results and also graphically represented in Fig.4.

Table.4: Compressive strength test results of concrete mixes M1 to M5

Concrete Mix designation	Ce me-nt	Spent Catalyst	Fine Aggregate	Coarse Aggregate	Steel fibres	Average Compressive Strength Test results N/mm^2
M1	100 %	----	100 %	100%	----	37.30
M2	85%	15%	100 %	100%	----	41.35
M3	85%	15%	100 %	100%	0.2 %	42.05
M4	85%	15%	100 %	100%	0.3 %	40.00
M5	85%	15%	100 %	100%	0.4 %	38.10

https://dx.doi.org/10.24001/ijaems.3.6.12 ISSN: 2454-1311

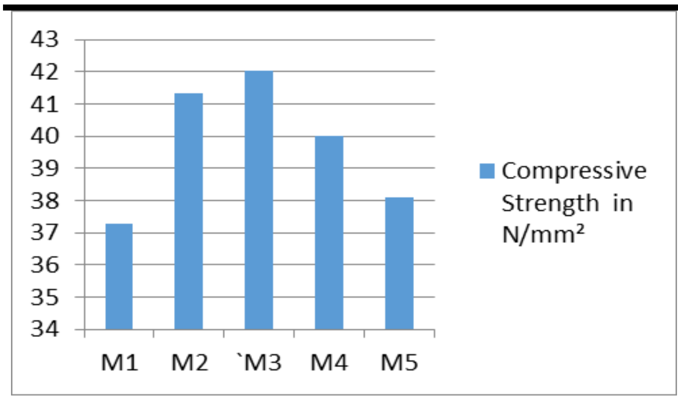

Fig. 4: Graphical representation of Compressive strength test results of concrete mixes M1 to M5

Table 5 shows the 28 days split tensile strength to concrete results and also graphically represented in Fig.5.

Table.4: Split tensile strength test results of concrete mixes M1 to M5

Concrete Mix Designati-on	Cement	Spent Catalyst	Fine Aggr-egate	Coarse Aggreg-ate	Steel fibres	Average Split tensile Strength N/mm^2
M1	100%	----	100 %	100%	----	4.5
M2	85%	15%	100 %	100%	----	5.16
M3	85%	15%	100 %	100%	0.2 %	5.25
M4	85%	15%	100 %	100%	0.3 %	5.00
M5	85%	15%	100 %	100%	0.4 %	4.76

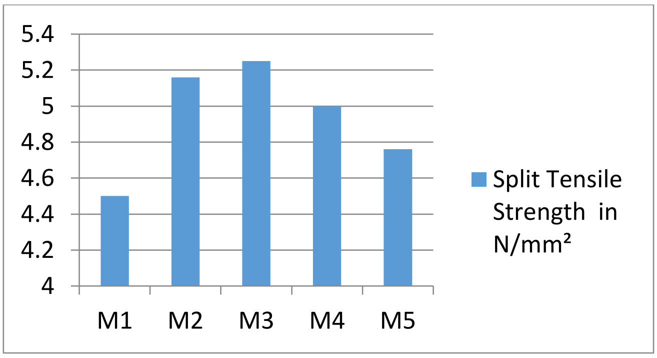

Fig. 5: Graphical representation of split tensile strength test results of concrete mixes M1 to M5

Table 6 shows the 28 days flexural strength to concrete results and also graphically represented in Fig.6.

Table.6: Flexural strength test results of concrete mixes M1 to M5

Concrete Mix Designa te-on	**Cement**	**Spent Catalyst**	**Fine Aggregate**	**Coarse Aggregate**	**Steel fibres**	**Average flexural Strength Test results N/mm^2**
M1	100%	----	100 %	100%	----	3.73
M2	85%	15%	100 %	100%	----	4.13
M3	85%	15%	100 %	100%	0.2 %	4.20
M4	85%	15%	100 %	100%	0.3 %	4.0
M5	85%	15%	100 %	100%	0.4 %	3.80

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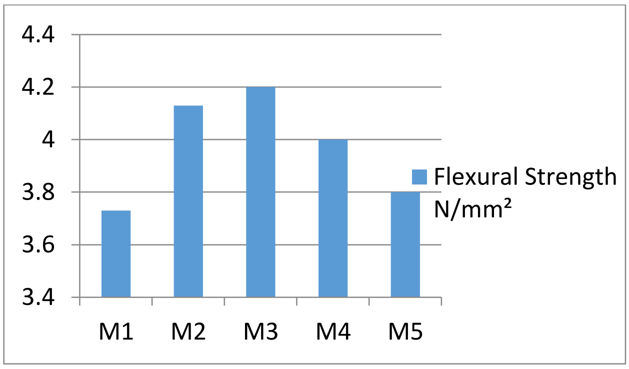

Fig. 6: Graphical representation of flexural strength test results of concrete mixes M1 to M5

V. DISCUSSION

The experimental results show that the concrete mix M3 containing 15% partial replacement of cement by spent catalyst and 0.20% steel fibers with an aspect ratio of 60 shows maximum compressive stress of 42.05N/mm^2, maximum split tensile strength of 5.25 N/mm2 and maximum flexural strength of 4.20 N/mm^2. The test results also show that the concrete mix M5 containing 15% partial replacement of cement by spent catalyst and 0.40% steel fibers with an aspect ratio of 60 shows minimum compressive stress of 38.10 N/mm^2, minimum split tensile strength of 4.76 N/mm^2 and minimum flexural strength of 3.80 N/mm^2. Finally the study show that 15% partial replacement of cement by spent catalyst with addition of 0.20% steel fibers with an aspect ratio of 60 produce satisfactory results. The strength properties of concrete decreases when the by volume addition percentage of steel fibres goes beyond 0.20 because of the steel fibres distortion in the concrete mixture.

VI. CONCLUSION

Based on the results, the following conclusion are drawn:

1) The experimental results show that the concrete mix M3 containing 15% partial replacement of cement by spent catalyst and 0.20% steel fibers with an aspect ratio of 60 shows maximum values for the concrete strength properties.
2) The maximum compressive stress recorded is 42.05N/mm^2, maximum split tensile strength is 5.25 N/mm^2 and maximum flexural strength is 4.20 N/mm^2.
3) The test results show that the concrete mix M5 containing 15% partial replacement of cement by spent catalyst and 0.40% steel fibers with an aspect ratio of 60 shows minimum values for concrete strength properties.
4) The minimum compressive stress recorded is 38.10 N/mm^2, minimum split tensile strength is 4.76 N/mm^2 and minimum flexural strength is 3.80 N/mm^2.
5) The study show that 15% partial replacement of cement by spent catalyst with addition of 0.20% steel fibers with an aspect ratio of 60 produce satisfactory results.
6) The compressive strength of M2- contained 15% by weight replacement of cement by spent catalyst- increased by 11% with reference to the control mix.
7) The compressive strength of M3- contained 15% by weight replacement of cement by spent catalyst and 0.2% by volume addition of steel fibres- increased by 13% with reference to the control mix.
8) The compressive strength of M4- contained 15% by weight replacement of cement by spent catalyst and 0.3% by volume addition of steel fibres- increased by 7% with reference to the control mix.
9) The compressive strength of M5- contained 15% by weight replacement of cement by spent catalyst and 0.4% by volume addition of steel fibres- increased by 2% with reference to the control mix.
10) The split tensile strength of M2- contained 15% by weight replacement of cement by spent catalyst- increased by 15% with reference to the control mix.
11) The split tensile strength of M3- contained 15% by weight replacement of cement by spent catalyst and 0.2% by volume addition of steel fibres- increased by 17% with reference to the control mix
12) The split tensile strength of M4- contained 15% by weight replacement of cement by spent catalyst and 0.3% by volume addition of steel fibres- increased by 11% with reference to the control mix.
13) The split tensile strength of M5- contained 15% by weight replacement of cement by spent catalyst and 0.4% by volume addition of steel fibres- increased by 6% with reference to the control mix.
14) The flexural strength of M2- contained 15% by weight replacement of cement by spent catalyst- increased by 11% with reference to the control mix.
15) The flexural strength of M3- contained 15% by weight replacement of cement by spent catalyst and 0.2% by volume addition of steel fibres- increased by 13% with reference to the control mix.
16) The flexural strength of M4- contained 15% by weight replacement of cement by spent catalyst and 0.3% by volume addition of steel fibres- increased by 7% with reference to the control mix.
17) The flexural strength of M5- contained 15% by weight replacement of cement by spent catalyst and 0.4% by volume addition of steel fibres- increased by 2% with reference to the control mix.

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