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Development of Self Compacting Concrete with Locally Available Spent Catalyst and Quarry Dust

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Abstract— **Due to environmental concerns, government agencies globally have enforced stringent laws for disposal of industrial waste. This has an immense pressure on industries to dispose and recycle their waste in an ecologically safe manner. Similarly, in Oman, the disposal of spent catalyst and quarry dust is a major concern to oil refineries and stone quarries respectively. In the present project work experimental investigation is carried out to see the possibility of locally available spent catalyst and quarry dust in the development of Self Compacting Concrete thereby reducing impact on the environment. Four mixes, such as Mix-A, Mix-B, Mix-C, and Mix-D with Water to Powder ratio of 0.8, 0.9, 1.0, 1.10 respectively, with constant Water to Cement ratio of 0.45 is used to determine the initial mix composition as per the European guidelines. Laboratory investigation was carried out in the Construction Material Testing Laboratory at Caledonian College of Engineering, Oman. Laboratory investigation revealed that the spent catalyst and quarry dust could be successfully used in the production of SCC.**

Keywords— ***Self Compacting Concrete, Spent Catalyst, Quarry Dust, Superplasticiser, Strength***

I. Introduction

Deterioration of concrete is a major concern all over the world. Reasons for deterioration of concrete are wrong practices followed on the site and one of them is poor compaction of concrete. To have durable concrete structure's concrete must be adequately compacted. Poor workmanship in concrete work is due to gradual reduction in the number of unskilled workers in the construction industry [1] and Oman is no exception. The construction industry is one of the largest industries in Oman and there is a need to develop concrete structures with high durability and safety. One of the solutions to obtain durable concrete structures is implementation of Self Compacting Concrete (SCC). SCC is a special type of concrete, which consolidate itself on its own weight without vibration and at the same time leading to no segregation and bleeding which leads to numerous advantages. It was first developed in the late eighties in Japan.

Further improvement in SCC was carried out at the university of Tokyo [2-4]. SCC can flow through heavily reinforced, deep and narrow sections with its own weight without segregation and bleeding, to achieve this, one of the basic requirements for the concrete mixes is to have high powder content and superplasticisers [5-8].

For the last two decades, tremendous work has been carried out by the researchers on SCC in developing high strength as well as low strength. Some worked on optimising the mix parameters, whereas other investigated the role of particle size distribution on SCC, few of them studied the effect of the water cement ratio on fresh and hardened properties of SCC, whereas others investigated the effect of material fines and content in SCC [5, 9-14].

Disposal of industrial wastes is the major concern for the industries due to environmental restrictions. This has led many researchers to use industrial waste, such as fly ash, ground granulated blast furnace slag, iron slag, rice husk ash, marble powder, quarry dust, construction demolition waste, limestone quarry dust, tyre rubber waste, bagasse, recycled aggregates, saw dust, limestone and chalk to develop advanced and special concretes. These industrial by-products are successfully used in isolation or in combination in developing SCC [7,8,15-28].

The disposal of spent catalyst is of major concern to oil refineries in Oman, similarly quarry dust. Using spent catalyst and quarry dust in present project work leads to an alternate waste management with a sustainable approach, thereby reducing impact on the environment. Hence, there is a need to study SCC with these materials. In the proposed project work, an effort is made to develop SCC using locally available spent catalyst and quarry dust. Spent catalyst is generated from the cracking of petroleum in oil refineries. The generated spent catalyst is classified as a waste material consisting primarily of silicates, aluminates and other secondary elements. Quarry dust is a by-product generated while crushing granite rocks for the production of coarse aggregates for various construction purposes.

II. Experimental Investigation

This chapter discusses the materials used, their properties, and mix design methods to arrive at the initial proportions of all the constituents used in production of SCC as per European guidelines [29,30]. Further, it discusses the experimental programme carried out on fresh paste and concrete to optimise the dosages of various constituent parameters to achieve fresh properties of SCC in terms of filling ability, passing ability and segregation resistance by slump flow, T_{50} slump flow, V-funnel, V-funnel at $T_{5\ minutes}$, L-Box and U-Box tests. Methods used to test the hardened properties of SCC in terms of compressive and split tensile strength are also discussed.

A. *Materials Used*

Cement: In the present investigation Ordinary Portland Cement (OPC) of 43 grades conforming to BS 12 is used.

Sand: Locally available washed sand having specific gravity 2.53 is used in developing SSC.

Aggregate: In the present work locally available natural aggregate having specific gravity 2.53 with 4-14 mm size is used.

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Spent Catalyst: Spent catalyst (SC) used in the present study is shown in Figure 1 is considered as a waste product generated from locally available oil refineries in Oman as a result of the cracking process of petroleum oil. Spent catalyst used in the present investigation is having a specific gravity of 2.49.

Quarry Dust: Quarry dust (QD) powder which is a waste material is used in present project work is obtained from local quarry plants here in Oman. The image of quarry dust having a specific gravity of 2.38 is used in the present investigation is shown in Figure 1.

Figure 1. a) Spent Catalyst b) Quarry dust

Water: Potable tap water supplied by the city municipality is used in the present investigation.

Super plasticiser: 'Pantharhit NQ' is used as super plasticizer (SP) in the present project work.

B. *Mix Design*

Most mix design methods for SCC have empirical bases and differ considerably from those used in conventional concretes. European Guidelines for Self-Compacting Concrete [29,30] as well as information from previous literature is used to determine the exact quantities of the mix content. Four mixes, such as Mix-A, Mix-B, Mix-C, and Mix-D with Water to Powder (WP) ratio of 0.8, 0.9, 1.0, 1.10 respectively, with constant Water Cement (WC) ratio of 0.45 is used to determine the initial mix composition as per the specification and guidelines for Self-Compacting Concrete [29,30].

The initial designed mix composition for SCC is shown in Table I. Based on this information, laboratory test on paste is carried out to determine the amount of powder and SP dosage required to have a homogeneous paste to avoid segregation during concrete flow. Once this condition satisfies the test on concrete is carried out to verify the properties of the initial mix composition with respect to the self-compatibility characteristics of SCC. Necessary, adjustments to the mix composition is made to fulfill the requirements of SCC. Once all requirements were fulfilled, the mix is tested at full scale in the Construction Material Testing Laboratory at Caledonian College of Engineering, Oman to verify both the fresh and hardened properties as per European guidelines [29,30].

C. *Experimental Setup*

There is no single test is capable of assessing all of the key parameters and a combination of tests is required to fully characterise the SCC mix [29,30]. In order to study the effect of initial mix composition (Table I) on fresh and hardened state of SCC for the proposed four mixes, test methods and standards given in [29,30] is adopted.

TABLE I. INITIAL MIX COMPOSITION EXPRESSED BY VOLUME (LITERS)

Ingredients	Mix-A	Mix-B	Mix-C	Mix-D
Cement	114.75	122.21	128.92	134.98
Water	162.66	173.24	182.74	191.33
Quarry dust	44.29	35.14	26.91	19.48
Spent catalyst	44.29	35.14	26.91	19.48
Super plasticizer	4.02	4.28	4.51	4.72
CA 10 mm	301.8	302.4	302.4	302.4
Sand	328.2	327.6	327.6	327.6
Paste content	370	370	370	370
Aggregates	630	630	630	630
Total	**1000**	**1000**	**1000**	**1000**
W/C ratio by weight	0.45	0.45	0.45	0.45
W/P ratio by volume	0.80	0.90	1.00	1.10

V-funnel test for mortar

This test is carried out to investigate the rheology of the paste in SCC as shown in Figure 2a. The V-funnel time for mortar must fall between 7-11 seconds [29,30]. To meet this criteria number of mortar pastes is prepared by adjusting the dosages of SP by trial and error for fixed WP ratio. The initial Superplasticiser to Binder ratio (SP/B) is taken as 1.2. After a number of trials, the modified dosages of SP to get the desired V-funnel flow time for the Mix-A, Mix-B, Mix-C and Mix-D is given in Table II.

TABLE II. MODIFIED DOSAGES OF SUPERPLASTICISER AND THE V-FUNNEL FLOW TIME OF MORTAR

Mix	Initial SP/B ratio by weight	V-funnel flow time (s) for initial paste	Modified SP/B ratio by weight	V-funnel flow time (s) for modified paste
Mix-A	1.2	72	16	8
Mix-B	1.2	68	9.9	9.7
Mix-C	1.2	64	4.5	7.5
Mix-D	1.2	11	2	9

Slump Flow Test

This test is used to assess the flowability and flow rates of SCC as shown in Figure 2b.

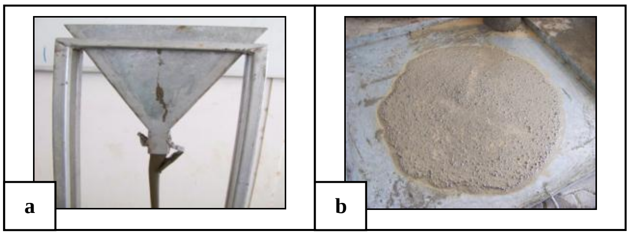

Figure 2. Experiment in progress for a) V-funnel test on mortar b) Slump flow test

V-funnel Test

This test measures the ease of flow of concrete. Lesser the time taken to empty the funnel greater is the flowability.

i) V-funnel Test

The filling ability of designed SCC is assessed using this apparatus.Experimental work in progress using V-funnel is shown in Figure 3.

ii) V-funnel at T_{5min} Test

This test is a continuation of V-funnel test. In this test V-funnel is refilled immediately after recording the flow time. This test is very much essential to test the segregation resistance of the designed SCC.

Figure 3. Experiment in progress for V-funnel test

L-box Test

This test method is used to check the passing ability of concrete through congested reinforcement without any vibration. L-box apparatus consist of vertical and horizontal section as shown in Figure 4a. The entire experiment is completed in five minutes. The blocking of coarse aggregate behind the vertical bars is observed visually. The acceptable blocking ratio of 0.8 is suggested for better passing ability [29,30], however, no suitable value is generally agreed.

U-box test

The U-box test is performed to check the filling ability of the SCC. The apparatus consists of a U shaped vessel divided into two sections. The apparatus used in the laboratory is shown in Figure 4b. The two sections are fitted with sliding gate which moves vertically.

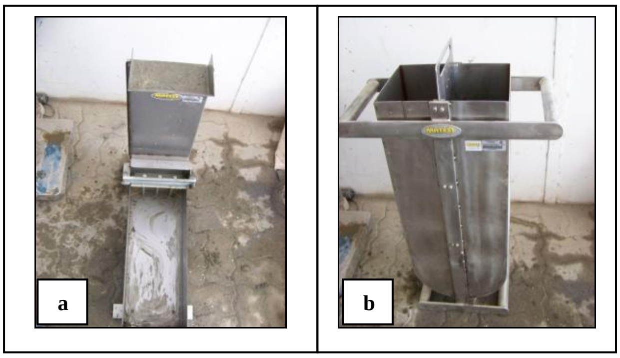

Figure 4. Experiment in progress for a) L-box test b) U-box test

D. *Mixing, Casting and Testing of Cubes and Cylinders*

Mix proportions of Mix-A, Mix-B, Mix-C and Mix-D is calculated within the tolerance of 10gms as per the design requirements and various test passed on fresh concrete. All this material is then added to the concrete mixer till we get the homogeneous mix. The concrete is then filled with cast iron cubes of dimensions 150 x150x 150 mm and cast iron cylinders of dimensions 150 x 300mm. While filling it is ensured that SCC is not compacted and filled with a single cast without any layering.Concrete cubes are used to check the compressive strength, whereas cylinders were used to measure the split tensile strength development of SCC.
All together 36 cubes and 36 cylinders were cast. After 24 hours the moulds are dismantled and SCC cubes and cylinders were placed in water for curing. The strength development at the age of 7, 14 and 28 days of curing.
Universal testing machine (UTM) of 100 ton capacity is used to test the compressive and the split tensile strength of cubes and cylinder respectively as shown in Figure 5.

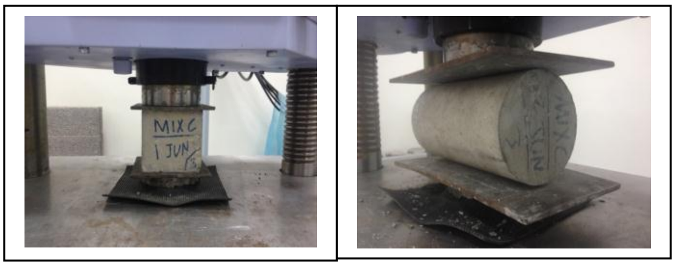

Figure 5. Compressive and split tensile strength test

III. Results and Discussion

A. *Fresh Concrete Behaviour*

Fresh concrete behaviour was tested to fulfil the acceptance criteria specified in European guidelines [29,30].

Analysis of Fresh Paste

The modified paste content for Mix-A, Mix-B, Mix-C and Mix-D are tabulated in Table III.

TABLE III. FINAL COMPOSITION OF PASTE CONTENT

Mix	WP ratio	Cement (kgs)	QD+SC (kgs)	Water (kgs)	SP by weight of Cement (%)	V-Funnel flow time(s)
Mix-A	0.8	361.47	215.67	162.66	16	8.0
Mix-B	0.9	384.97	171.11	173.24	9.9	9.7
Mix-C	1	406.1	131.06	182.74	4.5	7.5
Mix-D	1.10	425.19	94.87	191.33	2	9.0

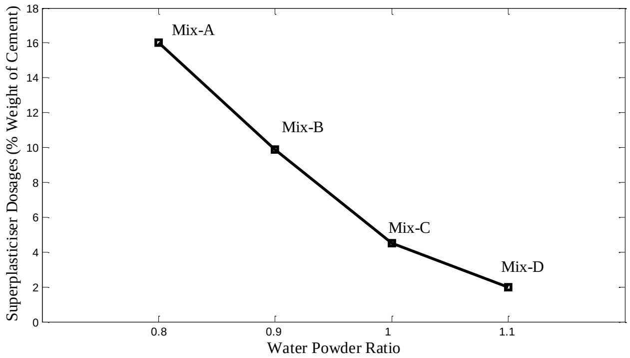

Figure 6. Water powder ratio Vs Superplasticiser dosages.

From Figure 6 and Table III, it is revealed that with the increase in WP ratio there is less requirement of SP to achieve the rheological characteristics required to produce SCC. Further, it is found that the amount of quarry dust and spent catalyst in the mix decides the dosages of SP. Higher the content of QD and SC more the requirement of SP to achieve the same flow characteristics. However, increase in cement content and water has demanded less dosages of SP to achieve the almost same V-funnel flow time for the SCC mix. Mix-A has the highest industrial waste (QD + SC) quantity and lower cement content, whereas Mix-D has the lowest quantity of industrial waste (QD + SC) with high amount of cement. Mix-D has demanded 2% of SP by weight of cement which is much less compared to Mix-A, Mix-B and Mix-C. Ho et al.[8] experience the similar behaviour using quarry dust in SCC.

Analysis of Slump Flow Test Result

A slump flow test is carried out to determine the flow ability of the trial mix design. The two characteristics of SCC measured in terms of flow time to reach 500mm concrete diameter and the final average diameter measured in two perpendicular directions are tabulated in Table IV. In all this four mixes the water cement ratio and aggregate contents remain constant.

TABLE IV. SLUMP FLOW FOR VARIOUS SCC MIX

Mix	WP ratio	Slump (mm)	Slump class	T_{500} (s)	Viscosity class
Mix-A	0.8	695	SF2	4.3	VS2
Mix-B	0.9	675	SF2	3.6	VS2
Mix-C	1	735	SF2	4.2	VS2
Mix-D	1.10	680	SF2	2.5	VS2

All mixes achieved a minimum slump flow of 650mm. Mix-A, Mix-B, Mix-C and Mix-D conform to the slump flow class SF2. Further, it is observed that the Mix-C has higher ability to fill the formwork with a largest slump flow of 735mm. However Mix-B has the lowest range of flow with a diameter of 675 mm. All mix passed T_{500} slump flow within five seconds and conform to viscosity class VS2. However, there is no direct relation established between the WP ratio versus flow diameter and T_{500} time.

Analysis of V-funnel and V-funnel at T_{5min} Test Results

The V-funnel test and V-funnel at T_{5min} test is carried out to investigate the filling and the segregation ability of SCC respectively. The test results obtained for Mix-A, Mix-B, Mix-C and Mix-D is shown in Table V.

TABLE V. V-FUNNEL AND V-FUNNEL TEST AT $T_{5MINUTES}$

Mix	WP ratio	V-funnel (s)	V-funnel test at $T_{5minutes}$ (s)
Mix-A	0.8	12.5	15.2
Mix-B	0.9	10.5	14.0
Mix-C	1	9.4	12.6
Mix-D	1.10	8.4	9.2

From Table V it is observed that all SCC mix have passed the filling ability except Mix-A as per EFNARC [29,30] guidelines. Standard V-funnel time is between 8-12 seconds. V-funnel $T_{5minutes}$ test values for Mix-B, Mix-C and Mix-D are within the range specified by EFNARC [29,30]. This revealed that there is no segregation in Mix-B, Mix-C and Mix-D. However, Mix-A has exceeded the $T_{5minutes}$ times of maximum 15seconds which leads to segregation.

Analysis of L-box Test Results

L-box test results are tabulated in Table VI and shown in Figure 7. The results clearly indicate that all four mixes can achieve good compactibility. The values shown in Table VI are within the tolerance values of 0.8 to 1.0. All mixes falls in a category of a PA2 class of passing ability type as per EFNARC [29,30].

TABLE VI. L-BOX TEST RESULTS FOR VARIOUS SCC MIX

Mix	Water powder ratio	Blocking Ratio	Passing ability type
Mix-A	0.8	0.86	PA2
Mix-B	0.9	0.91	PA2
Mix-C	1	0.90	PA2
Mix-D	1.1	0.82	PA2

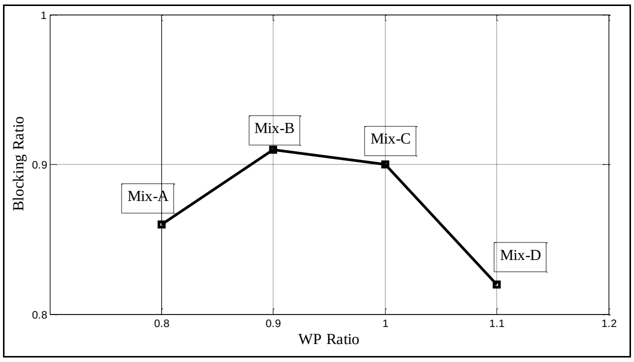

Figure 7. Relation between WP ratio and Blocking ratio

Analysis of U-box Test Results

U-box test results are tabulated in Table VII. From the test results it is revealed that for all WP ratios Mix-A, Mix-B, Mix-C and Mix-D have good passing ability. The experimental values range from 5-20mm, which are within the range of 30mm as specified in EFNARC[29,30]. Better passing ability is shown in the Mix-A in comparison to other mixes. This may be due to high SP dosage in the Mix-A.

TABLE VII. U-BOX TEST RESULTS FOR VARIOUS SCC MIX

Mix	WP ratio	Passing ability (mm)	Passing ability type
Mix-A	0.8	5	PA2
Mix-B	0.9	20	PA2
Mix-C	1	18	PA2
Mix-D	1.1	13	PA2

Further, it is noticed that the Mix-A has maximum content of SC and QD with high SP dosage. All mixes are falling in a category of PA2 as specified by EFNARC [29,30].

B. *Hardened Concrete Behaviour*

Compressive Strength of SCC

Compressive strength of Mix-A, Mix-B, Mix-C and Mix-D at the age of 7,14 and 28 days are tabulated in Table VIII and Figure. 8.

TABLE VIII. COMPRESSIVE STRENGTH OF SCC MIX

Mix	SP Dosage (% wt of Cement)	Compressive Strength in N/mm^2		
		7 days	*14 days*	*28 days*
Mix-A	16	3.480	3.512	3.199
Mix-B	9.9	30.836	35.610	40.720
Mix-C	4.5	32.803	36.902	39.856
Mix-D	2	41.881	38.867	49.647

From the Figure 8, it is observed that the decrease in SP dosage increases compressive strength of the SCC Mixes. Mix-D achieved maximum compressive strength of 49.647N/mm^2 at the age of 28 days, whereas Mix-A is a total failure. Compressive strength of Mix-A at the age of 28 days is noted as 3.199N/mm^2. One of the reasons for low strength is a high dosage of SP. In Mix-A 16% of SP in

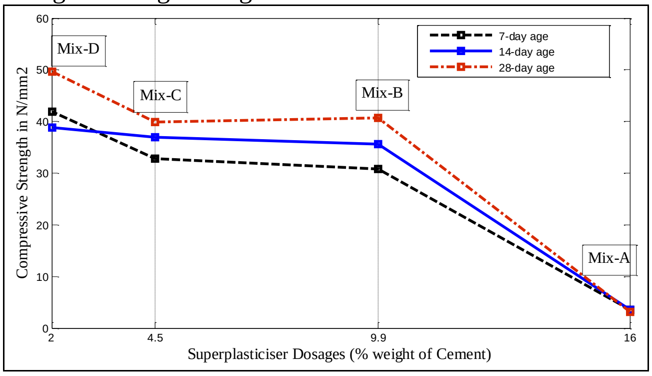

Figure 8. Compressive strength at the age of 7, 14, 28 days

terms of weight of cement are used, which is very high compared to previous studies carried out by researchers. In this Mix-A, it is also noted that it contains high amount of SC and QD with low amount of cement content. Whereas the exact opposite trend is noticed in the Mix-D. Mix-D has a WP ratio of 1.1 with higher cement content and the lowest amount of SC and QD compared to Mix-A. Another important observation noted that Mix-A has failed to pass the V-funnel and V-funnel at $T_{5minutes}$ test and the values obtained were above the standard norm suggested by EFNARC [29,30]. This result shows that Mix-A is poor in segregation resistance. All this aspect could be affecting the strength formation of Mix-A. Such behavior is not seen in other mixes, such as Mix-B, Mix-C and Mix-D with WP ratio 0.9, 1, and 1.10. However, in all SCC mixes it is found that there is an increase in compressive strength with age of concrete.

Split Tensile Strength of SCC

The results of split tensile strength are given in Table IX and Figure 9.

TABLE IX. SPLIT TENSILE STRENGTH OF SCC MIX

Mix	SP Dosage (% wt of Cement)	Split Tensile Strength in N/mm^2		
		7 days	*14 days*	*28 days*
Mix-A	16	0.3726	0.2477	0.5043
Mix-B	9.9	2.3548	2.9195	3.0218
Mix-C	4.5	2.3655	2.6951	2.9986
Mix-D	2	2.8336	2.9261	3.2534

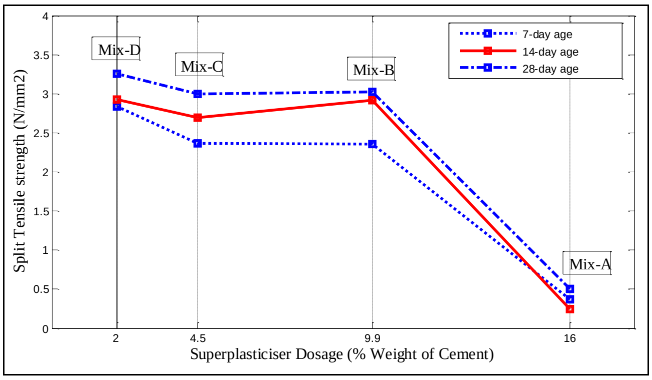

Figure 9. Split tensile strength at the age of 7, 14, 28 days

As discussed above, a similar trend is shown in the development of split tensile strength. Mix-A has poor split tensile strength and completely failed compared to other mixes. The reason could be the same as discussed in compressive strength of concrete. At the age of 7-days the split tensile strength for Mix-A is found to be 0.3726N/mm^2. At the age of 14-days it reduced to 0.2477N/mm^2. However, slight improvement is shown at the age of 28days. Mix-B, Mix-C and Mix-D have shown an increasing trend in split tensile strength development with the age of concrete. Mix-D recorded the highest split tensile strength of 3.2534N/mm^2. There is a direct relationship between the amount of cement and WP ratio in strength development. High content of cement and WP ratio, along with low amount spent catalyst and quarry dust resulted in high compressive and split tensile strength.

IV. Conclusions

In the present research work an effort is made to develop SCC with locally available industrial waste spent catalyst and quarry dust. It was found that the spent catalyst and quarry dust could be successfully used in the production of SCC. Four mixes viz. Mix-A, Mix-B, Mix-C and Mix-D was studied. Mix-A is a total failure in terms of compressive and split tensile strength. This may be due to the high percentage of SP dosage used to achieve the fresh concrete properties.Mix-D has performed better compared to other mix.

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"The disposal of spent catalyst and quarry dust is of major concern to oil refineries and stone quaries respectively in Oman. Using spent catalyst and quarry dust in present research work on developing self compactiong concrete leads to an alternate waste management with a sustainable approach, thereby reducing impact on the environment."

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