Fresh and Mechanical Properties of Concrete Containing Oil-Well Cutting Material

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***Abstract*—Oil-well cutting material (OWCM) is a waste generated during the process of oil-well drilling. Its disposal is costly and harmful to the environment. The chemical makeup for the material implies that it might be used as a partial cement replacement in concrete. It is high in calcium oxide, silica, and aluminum oxide, which are the main oxides found in raw materials used to produce cement. Replacing a part of cement by OWCM in concrete mixtures can directly reduce the quantity of the cement used which leads to decreasing the emission of carbon dioxide and solving the disposal problems for the OWCM as well. This process can be considered as a significant step in producing environmentally friendly concrete. This study focuses on investigating the fresh and mechanical properties of different concrete mixes that have different strength grades, containing different percentages of OWCM as a cement replacement. For this purpose, different concrete mixes containing 10%, 15%, 20%, 25%,30%, 35%, and 40% of OWCM as a cement replacement, besides the control Portland cement for the three different concrete strength grades, were prepared. After performing the slump and flow tests, cube specimens were cast and moist-cured for 3, 28, and 90 days and subjected to compression test, whereas 28-day moist-cured cylinder specimens were subjected to splitting tensile test. The test results have revealed that in spite of small reduction in strength with replacing cement by up to 20% of OWCM, the strength of the concrete remains within the designed strength grade ranges.**

***Index Terms*—Oil-well cutting material, Fresh properties, Compressive strength, Splitting tensile strength, Environment-friendly concrete.**

I. Introduction

The use of environment friendly materials in the engineering sector is a huge challenge. The environment is a major issue that must be addressed in all sectors, particularly engineering, because it has a direct impact on our lives.

Oil-well cutting material is formed during the drilling procedure of an oil-well. It has oil, heavy metals, biological materials, and dirt in it. Thousands of cubic meters of oil-well cutting material can be created during the drilling operation of a single well (Ghazi, et al., 2011). The majority of drilling businesses keep this trash in open yards with no treatment. Environmental standards require cutting storage to be isolated to prevent pollution of surface and subsurface water. As a result, oil-well cutting material waste management has become an environmental issue with an accompanying expense for oil corporations.

Oil-well cutting materials, which are high in calcium oxide, silicon oxide, and aluminum oxide, might be used as a raw material in cement production. Furthermore, the oil content may aid in the reduction of fuel consumption during the calcination and clinkerization processes (Al Dhamri and Rashid, 2019). The cement industry accounts for roughly 5% of worldwide man-made CO_2 emissions, with the chemical process accounting for 50% and fuel combustion accounting for 40% (Mahasenan, Smith and Humphreys, 2003, Andrew, 2018). The cement industry emits about 900 kg of CO_2 for every 1000 kg of cement produced (Mehta, 2001, Rubenstein, 2012, Benhelal, et al., 2013).

The environmental friendliness of concrete cannot be fully appreciated without taking into account that the cement and concrete industries can provide ideal homes for using enormous quantities of waste produced from other industries. The cement and concrete industries are uniquely positioned to eliminate many wastes from the environment whereas receiving significant economic and technical benefits. The use of industrial by-products as replacements for natural materials is widely encouraged in construction, thus allowing residual materials to be recycled and valorized, whereas at the same time-saving natural resources and energy. In cement production, residual materials can be used as substitute fuels, raw materials, and supplementary cementing materials that replace by cement (Al Dhamri and Rashid, 2019).

Fly ash, ground granulated blast furnace slag, and silica fume are the most commonly used by-product materials in concrete as a cement replacement (Sata, Jaturapitakkul and Kiattikomol, 2007). The optimum percentage of these materials used in concrete as a cement replacement for obtaining best mechanical properties are 20%, 35%, and 15%, respectively (Mohamed and Najm, 2017) and (Hannesson, et al., 2012). The use of these by product materials in Portland cement concrete improves the performance of the concrete in

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both the fresh and hardened states (Zabihi-Samani, Mokhtari and Raji 2018). Moreover, the other purpose of utilizing byproduct materials in concrete is to save money and getting environmental benefits. Using these materials in concrete mixtures will directly reduce the quantity of the cement used which leads to decreasing the emission of carbon dioxide and solving the disposal problems (Neville and Brooks, 1987) and (Chen, et al., 2010).

Petroleum and oil drilling companies manufacture many types of drilling fluid muds, which are employed as a carrier of rock cuttings from the earth layers during the drilling operation. This fluid mud's primary function is to pull cuttings to the surface for disposal during the drilling process, allowing the drilling operation to proceed deeper. Once the cuttings have been gathered at the surface, the combination of drilling fluid and earth cuttings is separated to remove the cuttings and allow the fluid to be reused in the drilling operation. This stage of segregation is repeated until the fluid can no longer be treated and must be discarded (Young, et al., 1991).

The disposed mud is known as oil-well cuttings material and collected in a mud waste dump. Because oil-well cutting material cuttings include oil, they are hazardous waste that should not be discharged into the environment without treatment and purification (Eldridge, 1996).

The cuttings include calcium, silica, and alumina, all of which are necessary components in the production of cement. Furthermore, the oil component provides the cuttings a calorific value, which may assist minimize fuel use during cement manufacturing. The use of these cuttings in cement would give an environmentally appropriate waste management. The extracted oil-well cutting material cannot be utilized directly in cement; yet, some pre-processing is necessary. The oil-well cutting material from drilling operations is wet material that contains a lot of water and maybe some oil. The cutting is initially transported to an especially designed-landfill. The cutting is first moved to a constructed landfill, which is open, exposed to direct sunlight, and generally located in the desert. First, the oil-well cutting material is simply let to dry in direct sunshine and high temperatures, and then, the sludge is transported to a semi-dry lined pit (Al-Maqbali, et al., 2016). The previous research focused on the use of oil-well cutting material beside the raw materials in the cement production process, whereas till the writing of the current research few published researches were existing regarding the use of oil-well cutting material as a cement replacement in concrete.

The current research focuses on replacing cement with oil-well cutting material which is a waste material produced from drilling Oil Wells to save the environment from this waste material from one side and to produce concrete that is friendlier to the environment than conventional concrete from the other side.

II. Materials and Methods

Ordinary Portland cement type I (42.5 MPa) obtained from Mass Company was used in this research. The physical properties and chemical composition of the cement used were summarized in Tables I and II, respectively.

The fine aggregate that was used in this research was natural river sand with a specific gravity of 2.7. Gravel with a maximum size of 12.5 mm and specific gravity of 2.67 was used as a coarse aggregate. The hyper plasticizer used in this research was polycarboxylate based under the trade name of Sika Viscocrete 5930.

The oil-well cutting material was obtained from Shewashok oil-well near Koya city/Erbil (Fig. 1a). The air-dried oil-well cutting material was milled in a rotary steel ball mill and sieved on sieve No. 200 (75 μm) (Fig. 1b). Then, the sieved powder was burned at a temperature of 600°C, as shown in Fig. 1c for the calcination purposes and burning the organic materials. The chemical composition of the oil-well cutting material is shown in Table III.

The concrete mixture containing seven different percentages of oil-well cutting material as cement replacement (10%, 15%, 20%, 25%, 30%, 35%, and 40%) was prepared beside the control mixture for three different concrete strength grade range mixes A (25MPa), B (35MPa), and C (55MPa) having water-cement ratios (w/c) of 0.5, 0.4, and 0.32, respectively. All the mixes were designed according to (ACI211, 2011), after that trial mixes were made and corrected material quantities were determined.

The hyper plasticizer in the mixes having 0.4 and 0.32 water/cement ratio was used for maintaining proper

TABLE I
Physical Properties for the Used Cement (Masscompany, 2021)

Physical properties	Test results
Fineness (specific surface) (cm^2/g)	3320
Specific gravity	3.17
Initial setting time (min)	100
Final setting time (min)	230
3 days compressive strength (MPa)	23
7 days compressive strength (MPa)	-
28 days compressive strength (MPa)	46.1

TABLE II
Chemical Compositions for the Used Cement (Masscompany, 2021)

Chemical composition of the cement used.	Content (%)
SiO_2	19.2
Al_2O_3	4.6
Fe_2O_3	2.6
CaO	61.5
MgO	3.5
SO_3	2.5
K_2O	0.7
Na_2O	0.2
Equivalent Alkalies (Na_2O+0.658 K_2O)	0.66
Loss on ignition (L.O.I)	2.7
Lime saturation factor (L.S.F)	98.1
Free Lime (%)	1.0
Main compounds (Bogue's equations)	
C_3S	58.4
C_2S	11.1
C_3A	7.8
C_4AF	7.9

TABLE III
Chemical Compositions of Oil-Well Cutting Materials

Chemical compositions	Mass percentage
BaO	30.5
SO_3	18.1
SiO_2	15.4
TiO_2	9.54
CaO	7.19
Al_2O_3	3.26
Fe_2O_3	2.83
MgO	2.74
ZrO_2	2.48
V_2O_5	1.98
Cl	1.22
K_2O	1.2
Other	3.56

workability. The mix proportions for 1 m^3 of concrete for the mixes having a water-to-cement ratio of 0.5, 0.4, and 0.32 are shown in Tables IV-VI, respectively. The slump and flow tests were performed for all the mixes in accordance to (ASTM C143/C143M –05a) and (BS 1881: Part 105: 1984), respectively (ASTMC143, 2021) (BS1881, 1984).

From each concrete mix 9 (100*100*100) mm cubes and 3 (100*200 mm), cylinders were prepared. The cube specimens were immersed in water for 3, 28, and 90 days, whereas the cylinders were only immersed for 28 days. The compression test was carried out under the BS 1881: PART 116: 83, (BS1881:116, 1984), whereas the indirect tension was carried out under the (C78, 2002) standard. The experimental process for this study was carried out at the materials of construction laboratory of the Faculty of Engineering, Koya University. The trail mix and the sample preparation (cubes and cylinders) for compression and splitting tensile tests are shown in Fig. 2a-c, respectively.

Fig. 1. (a) Oil-well cutting material (OWCM), (b) sieved OWCM, and (c) OWCM at the furnace.

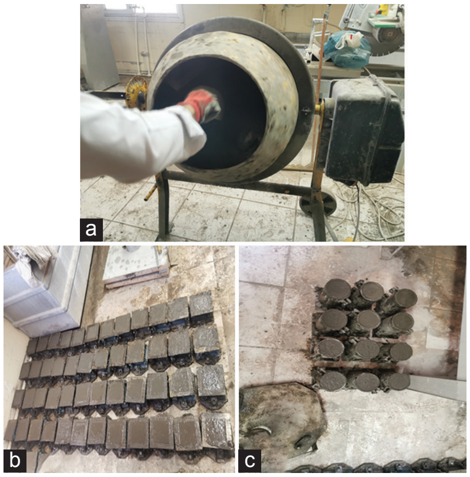

Fig. 2. (a) Trial mix, (b) cube sample for compressive strength, and (c) cylinder sample for splitting tensile strength.

III. Results and Discussions

A. Workability

The slump and flow values for w/c ratios 0.5, 0.4, and 0.32 are shown in Tables VII-IX, respectively. The slump for the control mixes of 0.5, 0.4, and 0.32 w/c ratio was 200 mm, 210 mm, and 220 mm, whereas the flow values were 550, 553, and 560 mm, respectively. By adding Oil-well cutting material, a slight promotion in a slump was recorded. The slump promotion became more significant in higher rates of replacement for cement by oil-well cutting material. To remain the slump in a constant range for the concrete mixes, a hyper plasticizer was used. The slump increase in the mixtures containing oil-well cutting material can be attributed to the large particle size diameter of oil-well cutting materials which were larger than cement particles. As oil-well cutting material particles have a lower surface area than cement particles, lower water is needed for wetting the surface area; hence, excessive water can contribute to increasing the slump values for the concrete mixes. For the concrete mixes of (0.32 w/c ratio), the slump values were almost constant, whereas the flow showed a slight reduction. This behavior is due to the technique of the flow test which depends on raising the flow table and dropping it, that the lower cohesiveness of the concrete mixes with higher replacement rates of oil-well cutting material plays the role.

B. Mechanical Properties

Compressive strength

Figs. 3-5 display the compressive strength results for grade A, B, and C concrete cubes having w/c ratios of 0.5, 0.4, and 0.32 and moist cured for 3, 28, and 90 days, respectively. The results show that the addition of oil-well cutting materials reduces compressive strength for all curing regimes when compared to the control specimen. The decrease in strength rises when the amounts of oil-well cutting materials are increased. By extending the curing period, all of the specimens achieve greater strength results. The strength reduction for grade A (0.5 w/c ratio) concrete at 3 days with 10%, 15%, 20%, 25%, 30%, 35%, and 40% of oil-well cutting materials as a cement replacement were 4.3%, 5%, 11.5%, 15%, 24.6%, 29%, and 39%, respectively. For 28 days, the strength reductions with 10%, 15%, 20%,

TABLE IV
Mix Proportions for 1 M^3 Concrete for Water Cement Ratio 0.5 Grade A

Sample name	% Oil-well cutting materials	Water (Kg)	Superplasticizer	Cement (Kg)	Oil-well cutting materials (Kg)	Sand (Kg)	Gravel (Kg)
A0	0	200	0	400	0	640	1000
A10	10	200	0	360	40	640	1000
A15	15	200	0	340	60	640	1000
A20	20	200	0	320	80	640	1000
A25	25	200	0	300	100	640	1000
A30	30	200	0	280	120	640	1000
A35	35	200	0	260	140	640	1000
A40	40	200	0	240	160	640	1000

TABLE V
Mix Proportions for 1 M^3 Concrete for Water Cement Ratio 0.4 Grade B

Sample name	% Oil-well cutting materials	Water (Kg)	Superplasticizer	Cement (Kg)	Oil-well cutting materials (Kg)	Sand (Kg)	Gravel (Kg)
B0	0	180	1.35	450	0	500	1130
B10	10	180	1.35	405	45	500	1130
B15	15	180	1.35	382.5	67.5	500	1130
B20	20	180	1.35	360	90	500	1130
B25	25	180	1.35	337.5	112.5	500	1130
B30	30	180	1.35	315	135	500	1130
B35	35	180	1.35	292.5	157.5	500	1130
B40	40	180	1.35	270	180	500	1130

TABLE VI
Mix Proportions for 1 M^3 Concrete for Water Cement Ratio 0.32 Grade C

Sample name	% Oil-well cutting materials	Water (Kg)	Superplasticizer (kg)	Cement (Kg)	Oil-well cutting materials (Kg)	Sand (Kg)	Gravel (Kg)
C0	0	160	3.6	500	0	560	1150
C10	10	160	3.6	450	50	560	1150
C15	15	160	3.6	425	75	560	1150
C20	20	160	3.6	400	100	560	1150
C25	25	160	3.6	375	125	560	1150
C30	30	160	3.6	350	150	560	1150
C35	35	160	3.6	325	175	560	1150
C40	40	160	3.6	300	200	560	1150

TABLE VII
Slump and Flow Values for Mixes with 0.5 w/c Ratio

Sample	% oil-well cutting materials	Slump (mm)	Flow (mm)
A0	0	200	550
A10	10	200	550
A15	15	200	550
A20	20	200	550
A25	25	200	550
A30	30	215	560
A35	35	215	560
A40	40	215	570

Table VIII
Slump Value for Mixes with 0.4 w/c Ratio

Sample	% oil-well cutting materials	Slump (mm)	Flow (mm)
B0	0	210	553
B10	10	220	560
B15	15	210	570
B20	20	210	570
B25	25	210	570
B30	30	210	570
B35	35	210	570
B40	40	210	560

TABLE IX
Slump Value for Mixes with 0.32 w/c Ratio

Sample	% oil-well cutting materials	Slump (mm)	Flow (mm)
C0	0	220	570
C10	10	210	550
C15	15	210	550
C20	20	210	550
C25	25	220	530
C30	30	220	530
C35	35	220	530
C40	40	220	530

25%, 30%, 35%, and 40% of oil-well cutting materials as a cement replacement were 1.7%, 6%, 15.8%, 18.8%, 29.4%, 30.46%, and 44.1%, respectively. However, the compressive strength reductions after 90 days of moist curing with 10%, 15%, 20%, 25%, 30%, 35%, and 40% of oil-well cutting materials as a cement replacement were 3.65%, 10.85%, 16%, 23.78%, 25.7%, 34.39%, and 42.2%, respectively.

For grade B concrete that has a 0.4 w/c ratio, the strength reduction at 3 days with 10%, 15%, 20%, 25%, 30%, 35%, and 40% of oil-well cutting materials as a cement replacement were 7.8%, 11.8%, 21.8%, 29.2%, 39.68%, 44.24%, and 44%, respectively. For 28 days, the strength reductions with 10%, 15%, 20%, 25%, 30%, 35%, and 40% of oil-well cutting materials as a cement replacement were 7.9%, 13.9%, 23.3%, 28.8%, 35.8%, 41.5%, and 43.1%, respectively. However, the compressive strength reductions at 90 days with 10%, 15%, 20%, 25%, 30%, 35%, and 40% of oil-well cutting materials as a cement replacement were 11%, 18%, 20.8%, 32%, 41%, 44%, and 45.5%, respectively.

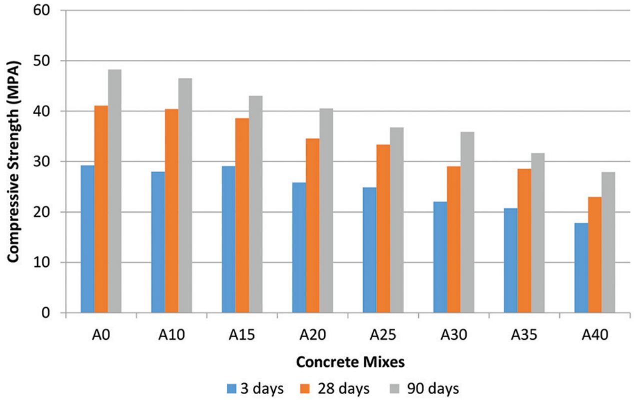

Fig. 3. Compressive strength for grade A concrete containing different percentages of oil-well cutting material made with 0.5 w/c ratio and moist cured for 3, 28, and 90 days.

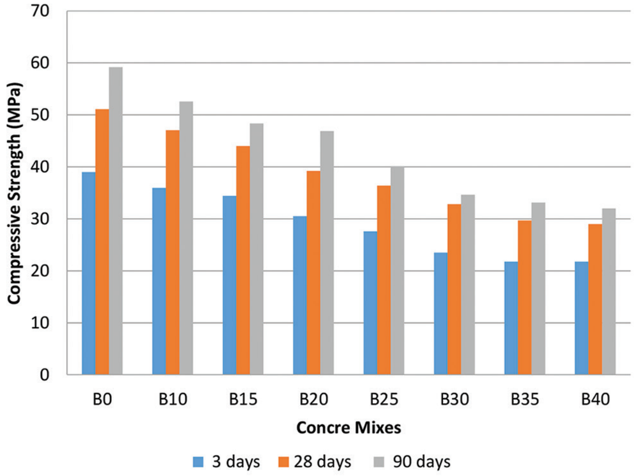

Fig. 4. Compressive strength for grade B concrete containing different percentages of oil-well cutting material made with 0.4 w/c ratio and moist cured for 3, 28, and 90 days.

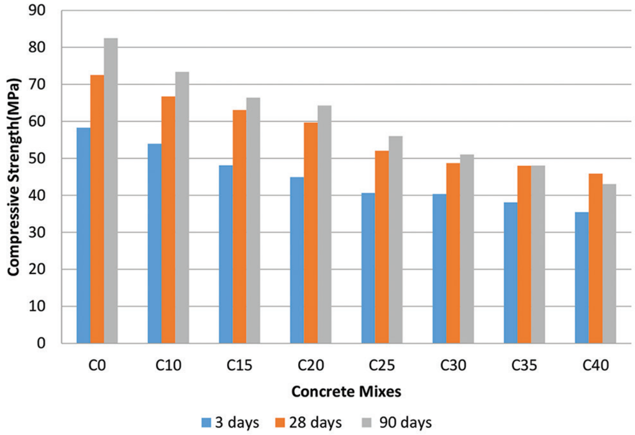

Fig. 5. Compressive strength for grade C concrete containing different percentages of oil-well cutting material made with 0.32 w/c ratio and moist cured for 3, 28, and 90 days.

The strength reduction for grad C concrete with 0.32 w/c ratio after 3 days of moist curing with 10%, 15%, 20%, 25%, 30%, 35%, and 40% of oil-well cutting materials as a cement replacement were 7.5%, 17.5%, 23%, 30.27%, 30.8%, 34.67%, and 39.1%, respectively. For 28 days, the strength reductions with 10%, 15%, 20%, 25%, 30%, 35%, and 40% of oil-well cutting material as a cement replacement were 7.9%, 13%, 17.72%, 28.24%, 32.57%, 33.86%, and 36.72%, respectively. However, the compressive strength reductions at 90 days with 10%, 15%, 20%, 25%, 30%, 35%, and 40% of oil-well cutting materials as a cement replacement were 11%, 19.5%, 22%, 32%, 38%, 41.74%, and 47.8%, respectively.

The reduction in compressive strength was less pronounced for lower replacement ranges in all concrete strength grades. The lower strength grades showed lower strength reduction than the higher strength grades. The higher the w/c ratio the lower reduction was recorded, in a way that with up to 25% replacement percentages, the strength remained within the designed strength grade range. The previous behavior of concrete is because the oil-well cutting material is working only as filler in concrete without having any pozzolanic activity for enhancing the compressive strength.

Tensile strength

The splitting tensile strength results for 28 days of moist cured cylinders are shown in Figs. 6-8, respectively. When compared to the control specimen, all of the specimens containing oil-well cutting materials have a lower splitting tensile strength. When the replacement percentages are raised, the loss in strength becomes more pronounced. For 0.5 water-cement ratio, the tensile strength reduction with 10%, 15%, 20%, 25%, 30%, 35%, and 40% of oil-well cutting materials as a cement replacement were 7%, 20.2%, 22.65%, 23.53%, 25.8%, 26.2%, and 27%, respectively.

For 0.4 water-cement ratio, the tensile strength reduction with 10%, 15%, 20%, 25%, 30%, 35%, and 40% of oil-well

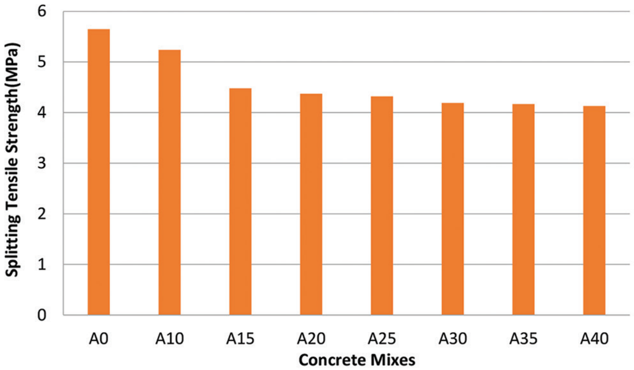

Fig. 6. Splitting tensile strength of Grade A concrete containing different percentages of oil-well cutting material made with 0.5 w/c ratio and moist cured for 28 days.

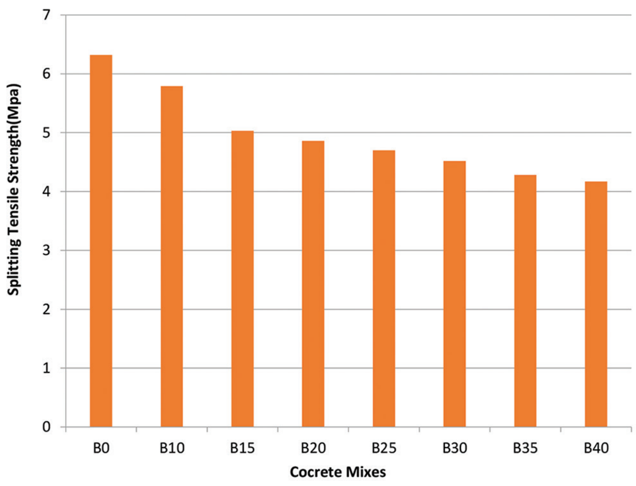

Fig. 7. Splitting tensile strength of Grade B concrete containing different percentages of oil-well cutting material made with 0.4 w/c ratio and moist cured for 28 days.

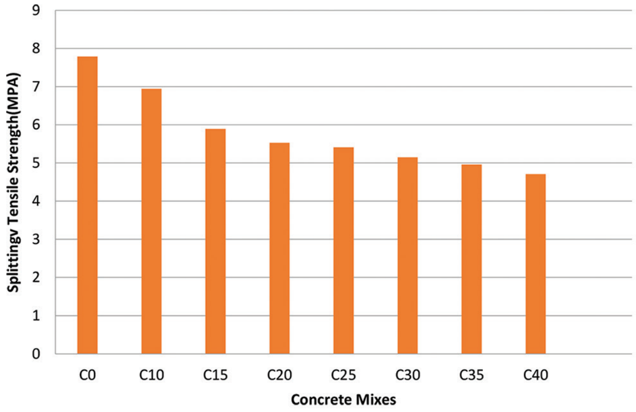

Fig. 8. Splitting tensile strength of Grade C concrete containing different percentages of oil-well cutting material made with 0.32 w/c ratio and moist cured for 28 days.

cutting materials as a cement replacement were 8%, 20%, 23%, 23.53%, 28%, 33.5%, and 34%, respectively.

For the 0.32 water-cement ratio, the tensile strength reduction with 10%, 15%, 20%, 25%, 30%, 35%, and 40% of oil-well cutting materials as a cement replacement were 11%, 24%, 29%, 30%, 34%, 36%, and 49%, respectively.

The reduction in splitting tensile strength rates was almost the same for grade A and B concretes, whereas grade C concrete showed somewhat less reduction rates. The reduction rates in splitting tensile strength were lower than that of compressive strength in higher replacement percentages.

IV. CONCLUSION

This research focuses on replacing cement with oil-well cutting material which is a waste material produced from drilling oil wells to save the environment from this waste material and produce concrete that is friendlier to the environment than the conventional concrete. From the experiment performed and the results obtained, the following conclusions can be drawn:

- Oil-well cutting material can be used in concrete as a cement replacement for producing concrete that is friendlier to the environment than conventional concrete.
- Replacing up to 20% of cement with oil-well cutting material results in a decrease in both compressive and splitting tensile strengths for all mixes in a manner that the strength remains within the designed strength grade ranges for compressive strength.
- Replacement rates higher than 20% result in significant strength reduction.
- The strength in lower w/c ratios for the replacement percentages is more acceptable than the higher w/c ratios.

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