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Using Reuse of Debris of Damaged Buildings by Armed Conflicts in Libya and Mill Scale Scrap to Produce Sustainable Concrete

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Abstract

In Libya, recycling of waste materials is not a common practice. The enormous amount of waste resulting from the destruction of the buildings due to the armed conflict, could be witnessed in most parts of the country. This paper aims to present more sustainable and environmental friendly concrete mix design by utilizing some of the locally available debris waste and mill scale scrape.

The previous studies carried out in this area favors the possibility of the effective utilization of locally available building debris in concrete mix design. In this research work, two types of sustainable materials (recycled concrete aggregates and steel mill scale) were incorporated to the concrete mix design. Firstly, the recycled concrete aggregates were used as a substitute of natural aggregates in certain proportions (i.e. 10, 30 and 60%). Secondly, steel mill scale was added to the concrete mixture as an alternative to replace a fraction of cement with the following different percentages i.e. 2, 6 and 10%.

The behavior of hardened concrete produced using these sustainable alternatives was investigated by performing the compressive strength, flexural strength of concrete and Ultrasonic Pulse Velocity (UPV) tests. The resultant mechanical properties of the concrete (produced from incorporating debris waste) found satisfactory which further emphasize on the possibility of reusing debris waste in concrete mix design for construction purposes.

Keywords: *Recycling, Sustainable, Environmental, Concrete, Aggregates, Mill Scale.*

1. Introduction

It is well known that concrete is the second most consumed material after water [1]. Concrete is the essential part of the building materials for different type of structures, ranges from schools, houses, factories, high-rise buildings, dams, airfields and many others. Keeping in mind the significant role of the concrete, it is utmost important to focus on its reuse and the new trends and possible way outs to come up with economical concrete mix designs with having better engineering performance. The particular concrete mix design should not only meet the anticipated performance but also comply with environmental, social and economic requirements. The application of the concept of sustainability and green building engineering design could help to achieve these objectives [2].
Sustainability and green buildings concept is based on the key factors including; maintaining environment by reducing the consumption of natural resources by reusing the wasted construction material. This could further provide employment opportunities for local labor, and the provision of utilizing building materials near to the project site and reduce the construction material transportation cost. The application of sustainable engineering, socially contributes to improve the economic standards of the local community and through educating and training them on the effective use of these materials.
Sustain means to keep a process going, and the objective of sustainability is that life on the planet can be sustained forever. There are three important components of sustainability: environment, society, and economy. To meet its aim, sustainable progress must provide that these three components stay balanced. At this time, the environment is the most important component and required significant attention to compensate the deterioration of our atmosphere worldwide by focusing on sustainable development approaches.[3]
Recently there is an enormous amount of increase in the concrete debris waste resulted from the demolition and reconstruction of buildings all over the world since the last decade of the twentieth century. The disposal of this kind of waste through dumping and accumulating in private landfills, could cause negative environmental impacts[4]. These construction wastes contain recyclable material like rebar, aggregate and concrete lumps with economic value. The utilization of such material in construction industry could play an axiomatic role in the progress of developing countries like Libya.
Despite the fact that these wastes might not lead to produce the concrete with desired strength, however, environmental factor remains the biggest motivation for the consideration of this practice in the construction of buildings with adequate strength.
According to the World Business Council for Sustainable Development (WBCSD: 2012) [5], the cement industry is responsible for 5% of carbon dioxide emissions. This fact indicates that the reduced production of cement would directly reflect on the emissions of carbon dioxide and other environmentally hazardous gases by incorporating varying degree of the amount alternative materials such as dust of silica, fly ash, slag, rice ash, glass crunched and many other materials [6].
In Libya, the concrete consumption is around 97% in the construing most of the structures ranging from houses to multistory buildings [7]. Moreover, many of the existing buildings in the country require rehabilitation, renovation or reconstruction. The demand of natural aggregates for these projects could pose additional negative environmental impact by demanding the new search of quarrying the alternative sources of aggregates to reduce in the country which is already facing the acute shortage of natural aggregate sources.

The negative environmental effect, resulted from the excessive use of natural aggregates could be observed in certain parts of Libya from the satellite images captured in different times in the recent past (see Figures 1-4). These images show the visual comparison of lands use changes in the vicinity of natural aggregate quarry locations before and after excavation of the natural aggregates. These images revealed a significant change in the area as the mining industry have consumed large zones of land that was a part of agricultural, residential, tourist activities.

Figure 1. Site for bricks quarry near the city of Surman, image before the excavation.

Figure 2. Site for bricks quarry near the city of Surman, image after the excavation.

Figure 3. Another site of bricks quarry near the city of Surman, image before the excavation.

Figure 4. Another site of bricks quarry near the city of Surman, image after the excavation.

Large amounts of mill scale result from the steel rolling factories, these amounts of wastes were estimated as 11000 tons annually, according to the statistics of the Libyan Iron and Steel Company (LISCO). [9]. These amounts of waste could be effectively utilized in the concrete to achieve the desired strength.

In 2011, the total debris waste produced as a result of the significant destruction in the recent armed conflicts in Libya, was estimated as more than 80 million tons, that exceeds the amount of construction waste produced by 15 European countries combined in that year (see Figure 5) [8].
Previous study conducted by Elazhari et al in 2013 has shown that there were few possibilities to rehabilitate and renovate few of the buildings. Moreover, the other studies outcomes also favors to

reuse of this type of enormous construction waste [8].

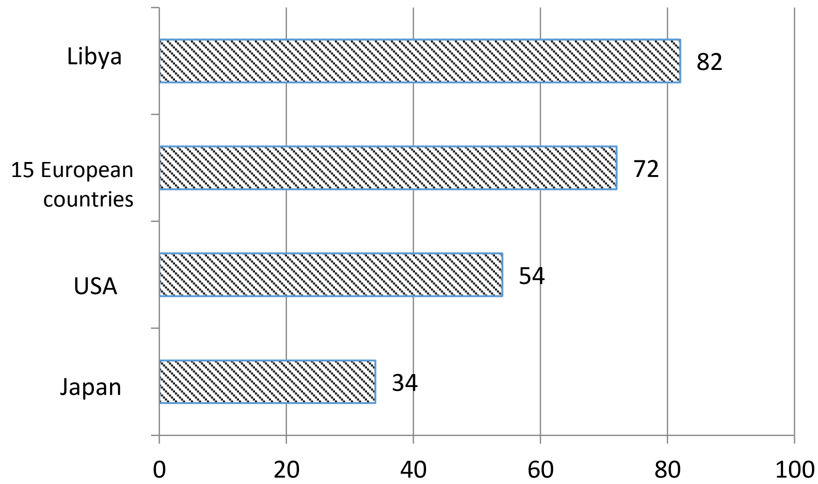


Figure 5. Construction waste produced for the year 2011 in million tons in different parts of the world in comparison with Libya **[8]**

The present study is carried out to emphasize on the proper use of recycled aggregates produced from demolished buildings waste and the residual material generated by the steel factories, in the concrete mix design.

In this study the compressive and flexural strength tests were performed on reformulated concrete of 60 days old. Ultrasonic Pulse Velocity (UPV) test were also conducted on the concrete samples to determine it mechanical properties.

2. Material and Methodology

To conduct the strength test on the reformulated concrete, the following materials were utilized in different proportions

- **Cement**: Ordinary Portland cement (N. 42.5) product locally in accordance with the Libyan specifications No. 340/2009 [9].
- **Water**: Tap water was used in making and curing the specimens as per Libyan specifications No. 1988 :294 [10].
- **Steel Mill Scale Scrap**: It is a powder of flaky steel particles of metallic-gray color with a spangle (see Figure 6). Mill Scale is considered as a by-product formed during the steel-making process and in particular during the hot rolling stage. Mill Scale material was brought from LISCO for this study; the Chemical properties and Particle-size analysis test results are illustrated in Table 1 and 2 respectively.

Table 1. Chemical Properties of Mill Scale Scrap.

Components	%Average Grade
Fe	67.00
SiO_2	3.37
AlO_3	1.10
CaO	2.45
P	0.08
S	0.05
MnO	0.57
H_2O	Maximum 5
Oil	0.9

Table 2. Particle-Size of Mill Scale Scrap.

Particle-Size (mm)	Passing (%)
0 to 12 mm	90
More than 12 mm	10

Figure 6. Mill Scale Scrap.

Figure 7. Collection of the Steel Mills Scale at Libyan Iron and Steel Company

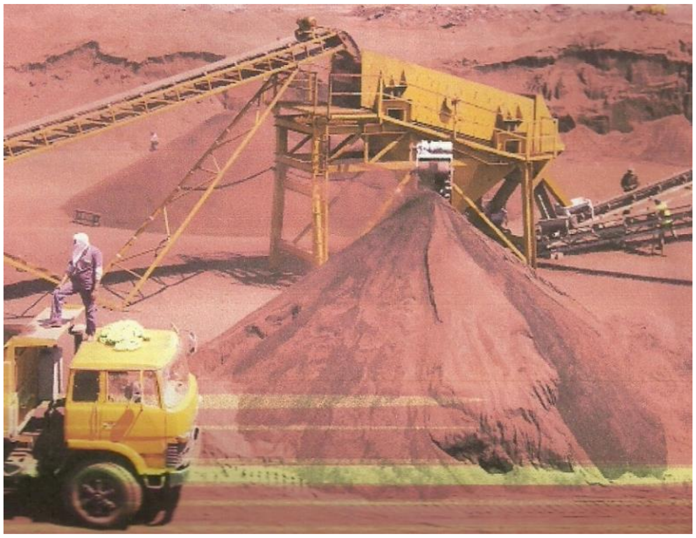


Figure 8. Transportation of the Steel Mills Scale at Libyan Iron and Steel Company

- **Fine Aggregates**: Natural aggregate available in Wedan in Al-Jufra area was selected for this research work. Table 3 presents the physical properties of fine aggregate and Table 4 shows the particle size distribution of the sand.

Table 3. Physical Properties of Fine Aggregates.

Property	Results
Moisture content (%)	0.17
Compaction factor (%)	2.83
Specific weight	2.65
Liquidity limit (%)	16.34

Table 4. Particle-Size of Fine Aggregates

Particle-Size (mm)	Passing (%)
2.5	100
1.25	99.4
0.63	84.6
0.31	44
0.16	14.6

- **Coarse Aggregates:**

Two types of coarse aggregates, including both natural and recycled concrete aggregates were used in this study. The natural aggregates produced from basaltic rocks available in Sokana at Al-Jufra area Libya and; the recycled concrete aggregates were obtained from breaking down the concrete waste of three different destructed military compounds (demolished as a result of aerial bombardment in military conflicts in 2011 in the Al-Jufra region (See Figures 9-11).

Figure 9. (Location 1) Main building of Defense Ministry Main building in Houn, Al-Jufra, Libya.

***Figure** 10.* (Location 2) Ammunition Store in Sokna, Al-Jufra, Libya.

Figure 11. (Location 3) Al-Jufra Air Base, Houn, Al-Jufra, Libya.

The breaking down of these blocks was first done manually at the site, and later the electrical crusher was used to crush the recycled concrete aggregate up to the desired size. The resulted aggregate was washed with clean water to remove any suspended material or dust particles. Finally, the aggregates were dried in an electronic oven at the temperature range of 100-110 C^{o}. The particles size distribution results of both natural and recycled aggregates are given in Table 5.

Table 5. Particle-Size of Coarse Aggregates

Particle-Size (mm)	**Passing (%)**	**Standard limits (%)** (BS 882: 1992)
40	100	100
20	85	100 - 90
10	35	60 - 30
5	0	10 - 0

A series of tests were carried out on the various types of natural and recycled aggregate samples; including specific weight, water absorption, crushing value and impact value. Figures 12-15 show a comparison between the physical properties of different types of aggregate combinations in this study. The figures also show the appropriate limits to be used in concrete mix design.

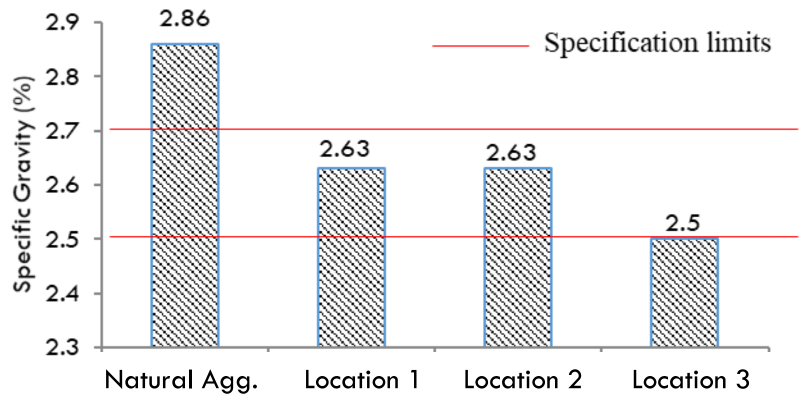


***Figure** 12*.Comparison Between the Specific Gravity of Aggregate Combinations Utilized for this Study.

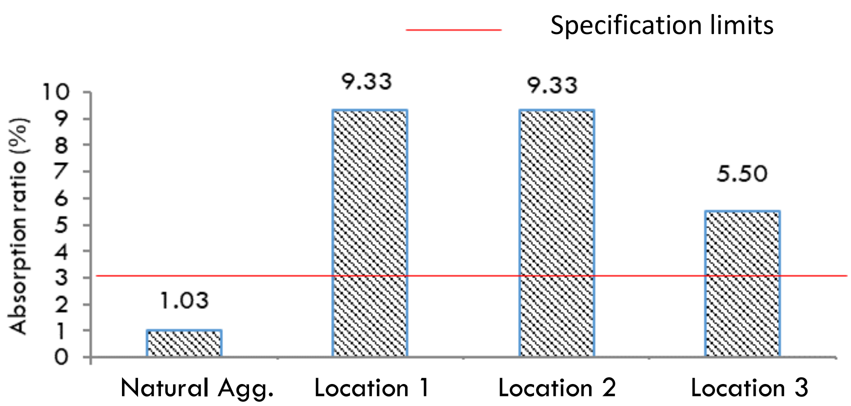


***Figure** 13*. Comparison Between Water Absorption of Various Aggregate Combinations Utilized for this Study.

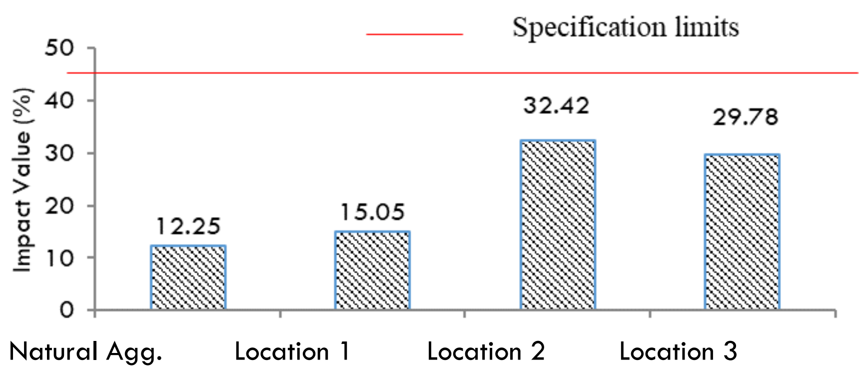


***Figure** 14*. Comparison Between Impact Value of various Aggregate Combinations Utilized for this Study.

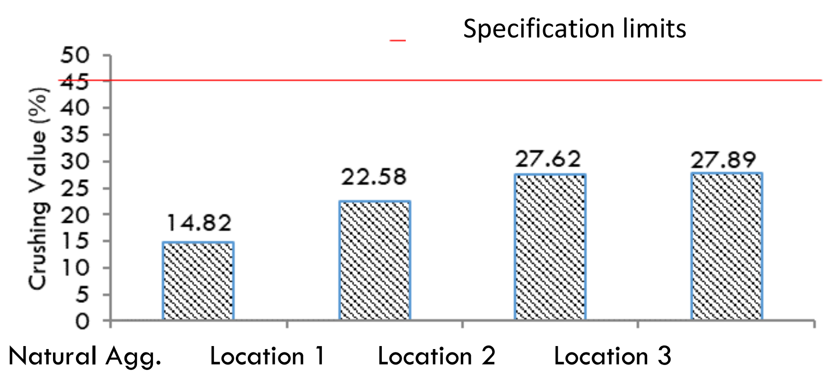
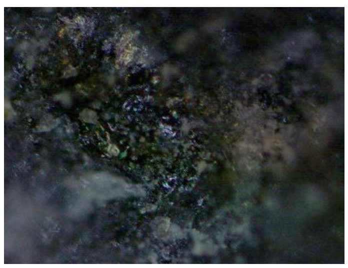
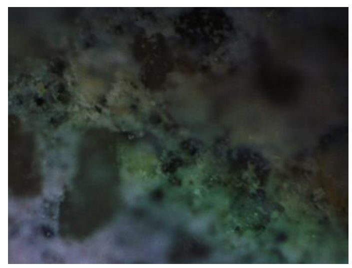
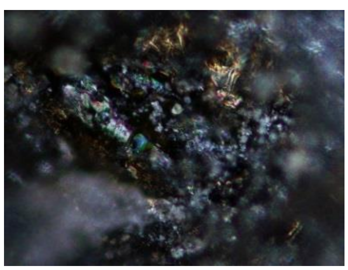
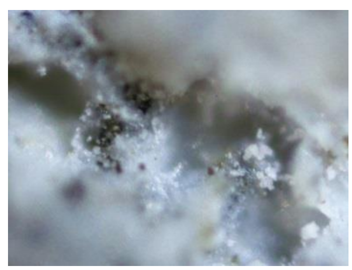


***Figure** 15*.Comparison Between Crushing Value of Various Aggregate Combinations Utilized for this Study.

According to the test results, it was noted that the specific weight of recycled aggregates was in compliance to the requirement of British Standards[11] except the natural aggregates, used in the Al-Jufra region that have a specific weight exceeding the limits of the standards. The rate of water absorption test reveals that the natural aggregates showed satisfactory results, while the recycled aggregates were found little high in absorption, this could probably be due to the amount of cement mortar layer within the aggregates. The impact and crushing values of aggregate results show the best coefficients for natural aggregates and recycled aggregate results were also found in compliance with the limits of standards [12, 13].

A microscopic examination of both natural aggregates and the recycled aggregates from Location 1 is shown in Table 6.

Table 6. The Microscopic Inspection of aggregates.

Lens Type	Natural Aggregates	Recycled Concrete Aggregates	Comments
Normal Lens			In both cases, aggregate sizes are irregular in shape that require more .water and cement
LU Plan Flour X/0.30 A10			The outer surface of the recycled aggregates contain fine particles cover on it in addition to the natural .aggregates
LU Plan Flour X/0.45 A20			More number of pores in the surface of recycled aggregates as compared to the .natural aggregates

Concrete Mix Design

Total 10 concrete mixt designs were utilized to study its behavior by varying the constituted material proportions (Table 7). As shown in the Table 7, the recycled concrete aggregates (RCA) (brought from location 1), were utilized as a partial substitution of natural aggregate (NA) with ratios of 10%, 30% and 60%. Additionally, Mill scale was used with the ratio of 2% 6% 10% as an alternative of cement weight.

Table 7. Mix Design Proportion for 1 m^3 of Concrete.

Concrete mix	Mill Scale**(%)**	**W/C(%)**	**RCA(%)**	**Components (Kg/m^3)**			
				NA	**RA**	**Sand**	**cement**
N-MS0	0	0.6	0	1280	0	640	350
N-MS2	2	0.6	0	1280	0	640	343
N-MS6	6	0.6	0	1280	0	640	329
N-MS10	10	0.6	0	1280	0	640	315
R10-MS0	0	0.6	10	1152	128	640	350
R10-MS6	6	0.6	10	1152	128	640	329
R30-MS0	0	0.6	30	896	384	640	350
R30-MS6	6	0.6	30	896	384	640	329
R60-MS0	0	0.6	60	512	768	640	350
R60-MS6	6	0.6	60	512	768	640	329

Strength Test Results and Discussions:

Furthermore, the compressive strength and flexural strength of concrete and Ultrasonic Pulse Velocity (UPV) tests were conducted to investigate the mechanical properties of the concrete.

Compressive Strength

The compressive strength tests on hardened concrete were conducted according to British Standards (BS 1881 part116: 1983) [14]. Figure 16 shows the results of compressive strength of concrete cube at the age of 60 days. The results revealed that the addition of the recycled concrete aggregates in different proportions do not reduce the compressive strength of the concrete significantly. For the specimens containing 10%, 30% and 60% of the recycled concrete aggregates, the compressive strengths were determined as 49.42 N/mm^2, 50 N/mm^2, and 46.19 N/mm^2 respectively, which is in accordance with the reference concrete value (i.e. 50.6 N/mm^2).

The effect of adding the steel mill scale in different proportions without recycled concrete aggregates was also investigated. The results show that the addition of 2% mill scale leads to decrease the compressive strength of concrete as compared to the reference samples. However, an increase in the compressive strength of concrete samples was noticed by using 6% and10% of mill scale in the concrete mix design. For instance the compressive strength of the concrete samples with 10% mill scale was obtained 49.32 N/mm^2 which is approximately equal to the reference concrete sample value (i. e. 50.6 N/mm^2).

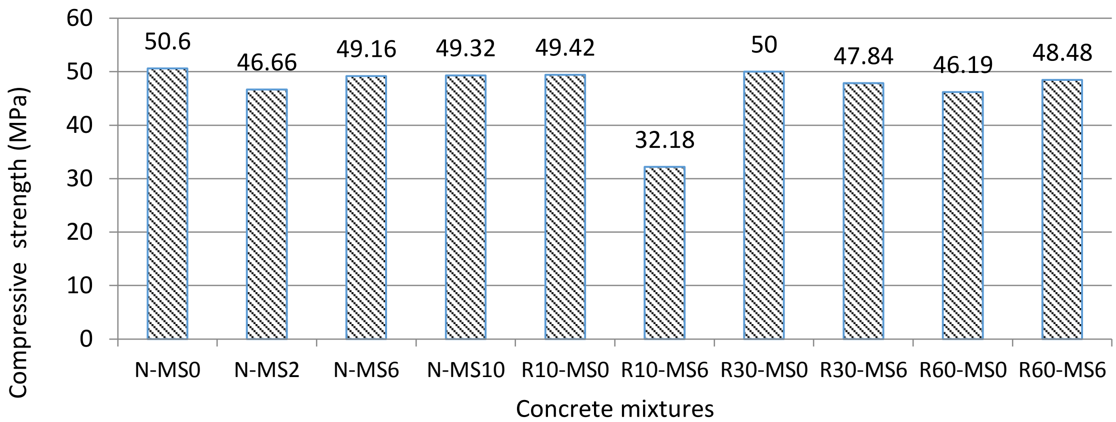


***Figure** 16*.The Results of Compressive Strength of Concrete at the Age of 60 Days.

Flexural Strength

The flexural strength Tests on hardened concrete were conducted according to ASTM Standards (ASTM:C78) [15]. The results presented in Figure 17 show an increase in flexural strength of the concrete with using 6% mill scale and 30% of recycled aggregates as compared to the reference concrete. This could happened because of the effect of mill scale addition that worked as a mineral fiber to resist tensile stress, that further helped in improving the strength of reinforced concrete. A decrease in the flexural strength of concrete was noticed for the concrete mix design having 30% of recycled concrete aggregates without mill scale.

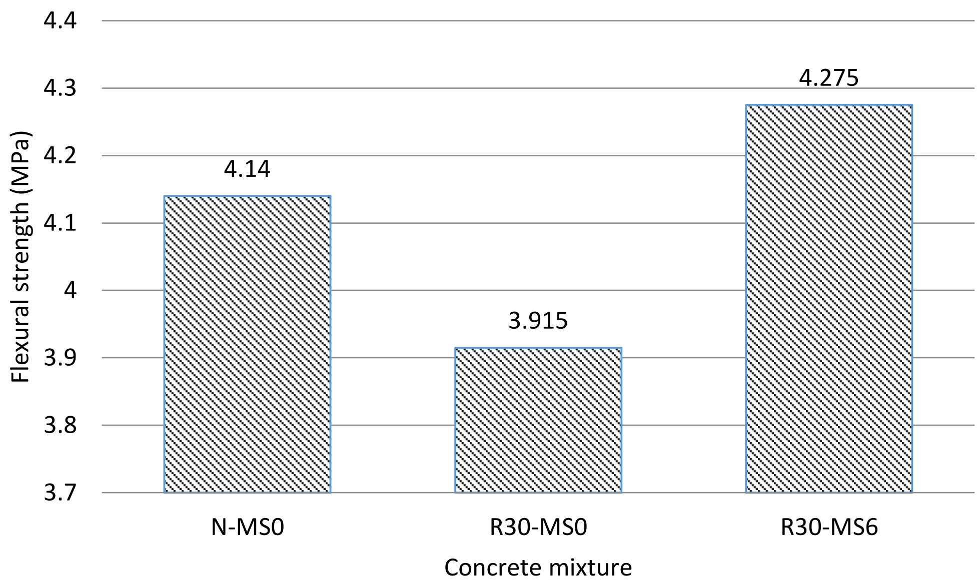


***Figure** 17*.The Results of Flexure Strength Tests**.**

UPV Test

UPV Test on concrete was conducted according to (ASTM: C597) [15]which is considered as one of the reliable non-destructive concrete tests. This test show the change in the mechanical properties of samples over the time[16].

Overall, the UPV results presented in Figures 18-20, show that the speed of UPV increases with the increase in the age of the concrete which in turn indicates the improvement in mechanical properties until the age of 60 days for all samples. The Figures also reveals that such concrete mixtures containing mill scale in their composition have a higher UPV speed than the mixtures containing recycled concrete aggregates. The reason could likely be the presence of conductive compounds (iron), which may have a role in the increase in velocity of UPV. In contrast the recycled aggregate likely makes the concrete more porous that could reduce the speed of the ultrasound waves[16].

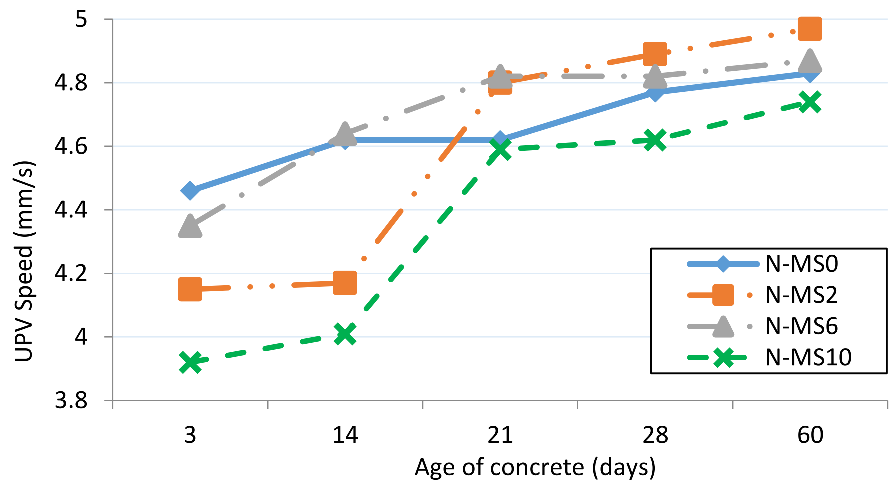


Figure 18.UPV Speed of Concrete Samples Containing Mill Scale only

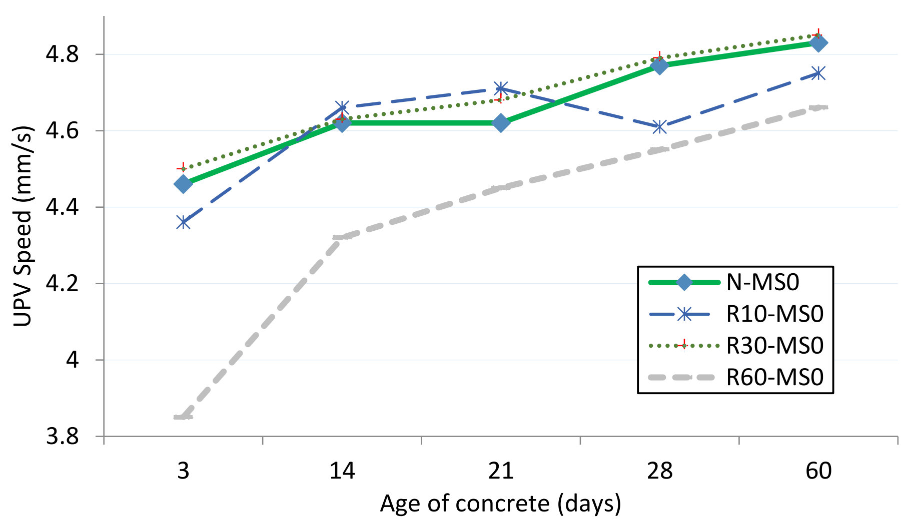


Figure 19. UPV Speed of Concrete Samples Containing Recycled Concrete Aggregates only

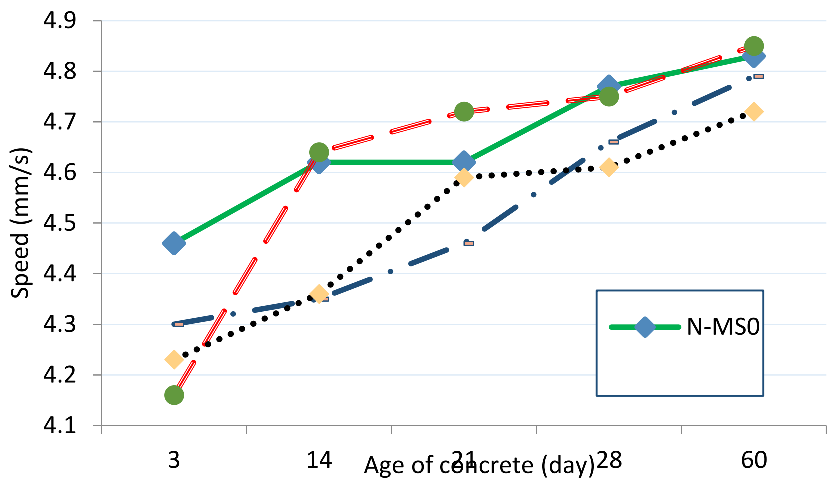


Figure 20. UPV Speed of Concrete Samples Containing both Recycled Concrete Aggregates and Mill Scale.

3. Conclusions

This study emphasis to prepare a reasonable concrete mix design with better mechanical properties with the addition of available debris waste. In this study the behavior of hardened concrete produced by using the sustainable alternatives was investigated in the country Libya by performing the compressive strength, flexural strength of concrete and Ultrasonic Pulse Velocity (UPV) tests. The resultant mechanical properties of the reformulated concrete are concluded below.

1. The substitution of 30% of the total weight of natural aggregates with recycled aggregates in the concrete mix gave the best results for the compressive strength of concrete.
2. The replacement of the cement in concrete containing recycled aggregates and mill scale in different percentages do not reduce its compressive strength tests significantly and still gave values close to the reference value concrete.
3. The inclusion of mill scale as a substituent of cement, combined with natural aggregates gives better compressive strength as compare to the concrete having recycled aggregates component only.
4. The addition of the mill scale also improved the flexural strength of the concrete. Indeed, the addition of 6% of mill scale as a substitute for cement, and 30% recycled aggregates as substituent of natural aggregates gave the reasonable values of the flexural strength for the concrete samples.

Overall the resultant mechanical properties of the concrete, obtained from incorporating debris waste and mill scale found satisfactory that emphasized on the possibility of reusing debris waste in concrete mix design for construction purposes in Libya. Such recommendations could certainly reduce the environmental issues associated with the new construction and related industry in the deadly war hit areas.

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