IJEIT
The International Journal of Engineering and Information Technology
journal homepage:www.ijeit.misuratau.edu.ly
2021 IECMU International Engineering conference-Misurata University

Influence of Ultrafine Steel Slag Powder Content Upon Cement Mortar

Abdullah M. Elsaedi
Department of Civil Engineering, Omar Al Mukhtar University
El Beida, Libya
gen7rudan@gmail.com

Hamza E. Benomran
Head Department of Civil Engineering, University of Derna
Derna, Libya
benomranham3a@gmail.com

Faraj A. Elhaddad
Mechanical Engineer at Libyan Cement Company
Derna, Libya
aslan.industriyel.faraj@gmail.com

Abstract— **Steel slag (Electric Arc Furnace Steel Slag) is a by-product left over from the conversion of iron to steel in steel industries. This paper reports the results of an experimental study on partial replacement of ordinary Portland cement (OPC) with steel slags powder produced in Libya (Libyan Iron and Steel Company). The effects of various replacement ratios of ultrafine steel slag powder to Portland cement (i.e., 10%, 20%, 30%, 40%, and 50%) on the workability, mechanical, physical and chemical properties were studied. The fineness of steel slag powder was standardized by using a 63 µm sieve. The properties of cement pastes and mortars with ultrafine steel slag powder were tested including water requirement of normal consistency, setting time, soundness, fluidity, dry bulk density, total porosity, water absorption capacity. compressive and flexural strength. The results showed that for cement pastes with ultrafine steel slag powder, the normal consistency water requirement were increased significantly. Both the initial setting time and final setting time were also accelerated than that of the control sample. The partial replacement of cement by ultrafine steel slag powder decreases the compressive and flexural strength, but increases the fluidity which improves the workability of the mortar. The results showed that the optimum content of ultrafine steel slag powder as a replacement of OPC was 10%.**

Index Terms: **Steel Slag powder, CO_2 reduction, Sustainability, Cement industry, waste management.**

I. INTRODUCTION

Zero waste politics aims to cut back the environmental burden of the world and save energy by recycling waste. The balance between the free-market economy and ecologically acceptable solutions is incredibly unstable and sensitive. Human health risk and survival depend upon this balance. Slag seems to be an honest option as a construction material, but like other similar waste types like ash, its application needs to be tired conjunction with controlling its environmental impact and dissemination of possibly harmful agents.

Received 1 Nov , 2021; revised 11 Nov, 2021; accepted 14 Jan, 2021.

Available online 24 Nov, 2021.

Steel slag, with its physical properties and controllable impact on the environment, has great potential to be included within the inventory of waste applied as construction material. This paper was prepared to get realistic and applicable results in order that it's incorporated and employed in the Libyan market.

The demand for cement has increased everywhere the planet which has created great pressure on the cement industry. The cement industry is one of the foremost important factors affecting temperature change and warming impacts, figure 1 shows Cement, iron, and steel Plants locations in Libya.

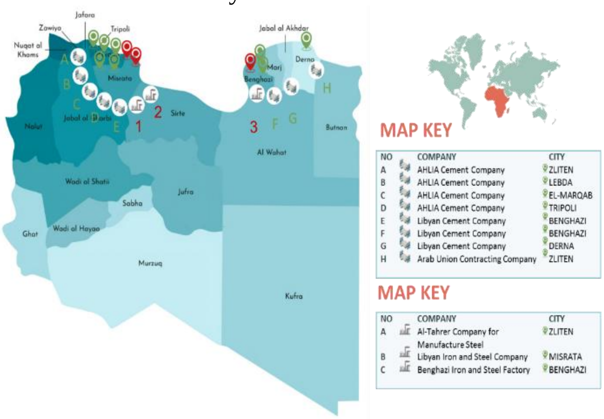

Figure 1. Cement, iron and steel Plants locations in Libya.

However, the technology that prepares steel slag for application within the cement industry may contribute to pollution. Therefore, care should be exercised within the production of cement from steelmaking slag. To be more precise, a study conducted within u. s. (south Camden, New York) showed that approximately 2%–13% of the full deposited stuff (PM) mass came from the preparation technologies during the production of slag into raw material for the cement industry [1].

It has now been proven that top-quality and sturdy concrete are often produced using blended Portland cement. the employment of this cement in Libya isn't well-known, and there are no comparative data to enable engineers to succeed in an informed decision on the short and long-run performance of this and other available cement systems. However, the necessity for permanently quality durable concrete in countries like Libya can't be overemphasized [2]. it's important to concentrate on the performance of the latest structures when selecting the materials and technologies that may be utilized in the present construction program.

None of the substitute materials for hydraulic cement mentioned above are produced in Libya. However, the country produces over 27,000 plenty of electrical conduction furnace (LSS) slag annually as a significant by-product of the iron and industry [3]. many thousands of plenty of slag is currently dumped over an outsized area of land where it's now a serious environmental problem.

Among the difficulties facing the method of using discharge furnace slag is that the difficulty of grinding, transporting and treating it within the event of early hydration and early resistance, which makes the employment of Libyan steel slag in replacement very expensive and not encouraging to the cement industry ...
Therefore, it absolutely was necessary to balance between environmental stability and economic feasibility, and this is often what this paper tries to get during a realistic and practical way in line with the principle of direct and cheap use.

II. MATERIALS AND METHODS

A. Materials

An ordinary Libyan Portland Cement CEM I 52.5N obtained from the Libyan cement company plant was used throughout the tests, and steel slag powder (SSP) is a non-commercial air-cooled electric-arc furnace steel slag produced in Libya as a by-product of the Iron and Steel Industry. The slag was supplied initially in the form of medium size (100mm to 400mm) rocks. Finally, the slag powder was sieved to pass 63 µm, in order to remove any remaining larger particles, Finally Gypsum was obtained from the Libyan Cement Company. It was air dried and mixed thoroughly in dry condition. It was passed through 90 micron sieve. Figure 2 shows Particle size distribution of materials Used (Sieve Analysis).

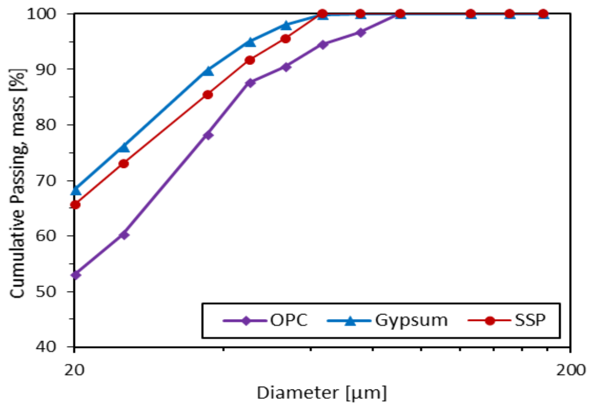

Figure 2. Particle size distribution of materials Used (Sieve Analysis).

Physical properties of cement, i.e., fineness, standard consistency, initial and final setting time, specific gravity and Bulk density are evaluated by the procedures given in BS EN 197-1[4].

However, no such specification exists for the use of steel slag. In the absence of a specification for steel slag powder, the physical and chemical data obtained for this material and its suitability as a cementitious material has been assessed with reference to [5], specification for Ground Granulated Blastfumace Slag for use with Portland cement. Standard specifications as shown in table 1.

Table 1. Physical properties of the materials used

Physical characteristics	OPC	Steel Slag powder
Fineness (% retained on 90 micron sieve)	0	0
Specific Gravity (g/cm^3)	3.15	2.707
Bulk density (kg/m^3)	2354.17	-
Loss on Ignition (%)	2.75	26.04
Standard Consistency (%)	28	-
Initial Setting Time (min)	130	-
Final Setting Time (min)	180	-

B. Methods

According to the objectives of this paper, different mixes were produced by replacing five different percentages (0%, 10%, 20%, 30%, 40% and 50%) of steel slag powder (SSP)

A simple approach has been adopted which involves partial replacement of the Ordinary Portland Cement (OPC) used in the 100% OPC control samples (Mix C), with an equal weight of steel slag powder (Mix L). The levels of OPC replacement were 10%, 20%, 30%, 40% or 50%.

The following notation was used in identifying the various mixes. A letter prefix was used to denote the OPC replacement level and a letter suffix indicate the Gradient. This is shown schematically below:

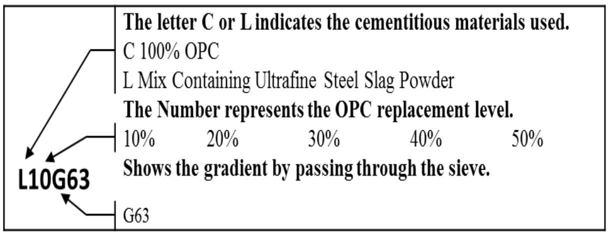

Figure 3. Scheme of mortar mixes for cement replacement

C. Cement paste mixes

Cement paste mixes were used in the preliminary stages of the study in order to have an understanding of the fresh behaviour and hardened properties of the materials under investigation. These pastes were also used in the evaluation of the Standard consistence, setting times and Soundness.

D. Cement mortar mixes

Direct replacement portion of Portland cement by ultrafine steel slag powder by mass, which mainly consists of modifying an existing Portland cement mix to include ultrafine steel slag powder without other adjustments.

Table 2. Quantities and proportions of mixing materials for mortar mixes

Sample	Cement	Steel Slag Powder	Gypsum	Water	CEN Standard sand
	g	g	g	mL	g
C	450	0	0	225	1350
L10G63	405	42.3	2.7	225	1350
L20G63	360	84.6	5.4	225	1350
L30G63	315	126.9	8.1	225	1350
L40G63	270	169.2	10.8	225	1350
L50G63	225	211.5	13.5	225	1350
L100G63	0	423	27	225	1350

The primary fresh and hardened properties such as wet density, flow value, dry bulk density, fresh bulk density, compressive strength, flexural strength, apparent porosity and water absorption Capacity of the cement mortar specimens were determined to comprehend the total experimental data generated. The testing procedures followed to determine the above mentioned properties are briefly explained below in table 3.

Table 3. Details of the tests performed

S. No.	Test Parameter	Method of test
1	Chemical analysis	BS EN 196-2:2013
2	Standard consistence	BS EN 196-3:2016
3	Setting times	BS EN 196-3:2016
4	Soundness	BS EN 196-3:2016
5	Consistence of fresh mortar (by Flow table)	BS EN 1015-3:1999
6	Bulk density of fresh mortar	BS EN 1015-6:1999
7	Dry bulk density of hardened mortar	BS EN 1015-10:1999
8	Vacuum Saturation Porosity	ASTM C642-97
9	Compressive strength	BS EN 1015-11:2019
10	Flexural strength	BS EN 1015-11:2019

III. Results and Discussion

Chemical Composition, Cement modulus and Main Compounds

The analysis of chemical compounds of ultrafine Steel Slag powder samples was done by the (S2 RANGER) device manufactured by (BRUKER) company, which was calibrated before use, and which analyzes by using x-rays.

The chemical composition of ordinary Portland cement was compared with ultrafine steel slag powder, and this comparison is the basis for the concept of partial replacement. It is noted that most of the oxides are present in both compounds in varying ratios as shown in figure 4.

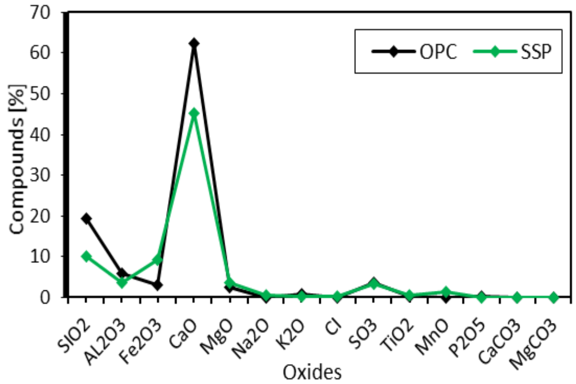

Figure 4. Chemical Compounds of the cement and ultrafine steel slag powder

Table 4. Chemical Compounds of the cement with ultrafine steel slag powder

Compounds %	Formula	OPC	SSP
Silicon dioxide	SIO_2	19.34	10.22
Aluminium oxide	AI_2O_3	5.8	3.70
Ferric oxides	Fe_2O_3	3.19	9.28
Calcium oxide	CaO	62.44	45.26
Magnesium oxide	MgO	2.47	3.49
Sodium oxide	Na_2O	0.08	0.44
Potassium oxide	K_2O	0.9	0.17
Free Lime	CI	0.005	0.38
Sulphur trioxide	So_3	3.69	3.44
Titanium oxide	Tio_2	0.36	0.52
Manganese oxide	MnO	0.046	1.36
Phosphorus pentoxide	P_2O_5	0.2	0.00
Calcium carbonate	$Ca\ CO_3$	-	-
Magnesium carbonate	$Mg\ CO_3$	-	-

Loss On Ignition of cement and ultrafine steel slag powder is not taken as a main parameter. The main purpose of using Loss On Ignition is for raw materials, but it is necessary as an indicator of the percentage of the material and its raw materials Loss On Ignition, as shown in Figure 5.

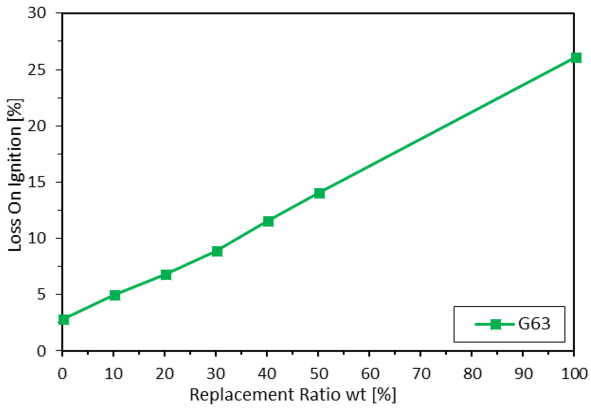

Figure 5. Loss On Ignition of motor with ultrafine steel slag power

Since the specific gravity of cement is 3.15 g/cm^3 and the specific gravity of ultrafine steel slag powder is 2.707 g/cm^3, therefore, the replacement samples that were calculated accurately are linearly proportional as shown in the figure 6.

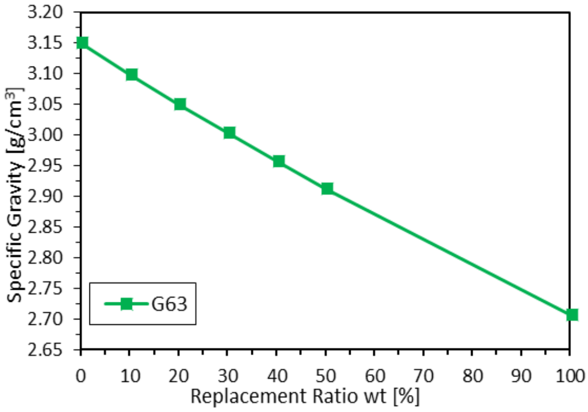

Figure 6. Specific Gravity of the cement with ultrafine steel slag powder

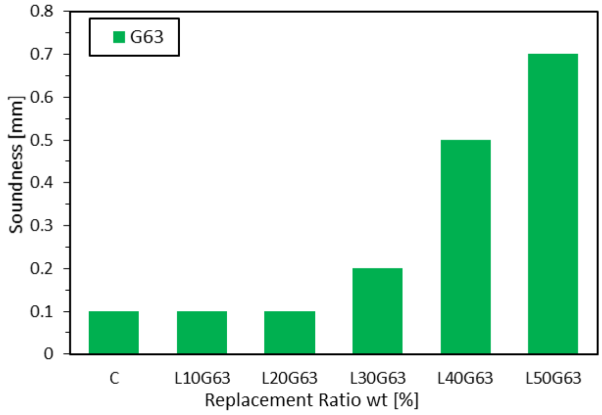

Figure 8. Soundness of motor with ultrafine steel slag power

Normal Consistency Water Requirement, Setting Times and Soundness

The water requirement decreases at the replacement ratio of 10% and then becomes stable up to 20% and then begins to increase significantly as the ultrafine steel slag powder becomes dominant over the mixture and due to its ultra fineness, it requires more water than cement.

The initial and final setting time accelerated very slightly with the increase in the replacement ratio. The reason for this may be the amounts of water added in the mixture with each replacement ratio. Figure 7 shows the setting time and Water Consistency of motor with ultrafine steel slag power

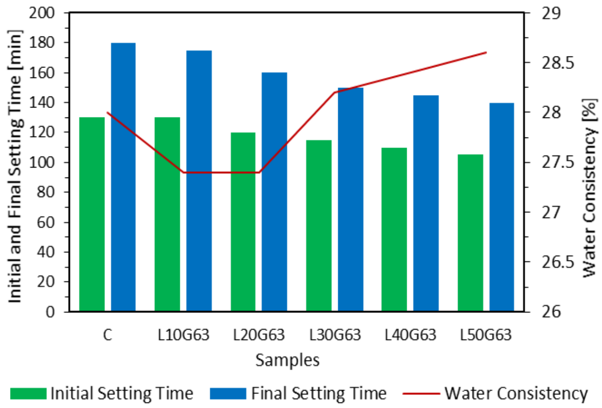

Figure 7. setting time and Water Consistency of motor with ultrafine steel slag power

The Soundness of the mixture paste was measured at each normal consistency water ratio, and as shown in Figure 8, the Soundness increases with the increase of the replacement ratio very slightly, and the Soundness effect may not be obvious because the cement used has a very small amount of Soundness, which makes it difficult to observe the real effect of ultrafine steel slag powder on Soundness of cement pastes.

Consistence and Bulk Density of Fresh Mortar

Due to the constant ratio of water to cement and ultrafine steel slag powder (binder) the fluidity of the mortars without steel slag powder is relatively low. However, the fluidity of the mortars increases with the cement replacement ratio. When the cement replacement ratio is 20%, the fluidity of mortars containing ultrafine steel slag powder is approximately 16 mm higher than that of mortars without ultrafine steel slag powder. These results indicate that using ultrafine steel slag powder as a mineral admixture could improve the fluidity of mortars, which is beneficial for the workability of mortar and concrete. This may be due to that the activity of ultrafine steel slag powder is lower than that of cement. Figure 9 shows the fluidity of the mortar with ultrafine steel slag power.

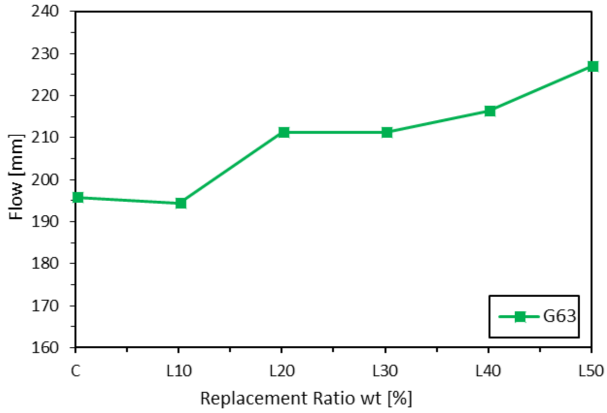

Figure 9. Fluidity of motor with ultrafine steel slag power

Due to the constant ratio of water to cement and steel slag (binder), the bulk density without ultrafine steel slag powder is relatively high. However, the bulk density decreases with the cement replacement ratio. When the cement replacement ratio is 20%, the bulk density of fresh mortar containing ultrafine steel slag powder is about 34 kg/m3 lower than that of mortar without ultrafine steel slag powder. These results indicate that using ultrafine steel slag powder as mineral additives can reduce the bulk density of cement mortar. Figure 10 shows the bulk density of fresh mortar.

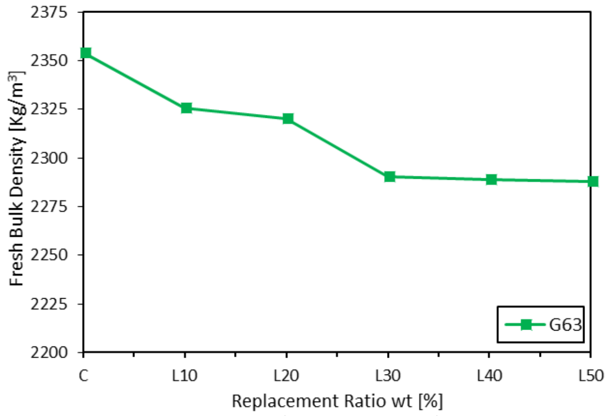

Figure 10. Fresh Bulk Density of motor with ultrafine steel slag power

Dry Bulk Density, Total Porosity and Water Absorption Capacity

Figure 11. Dry Bulk Density of motor with ultrafine steel slag power, for all replacement samples, the dry bulk density increases with the age of 28 days very significantly and then begins to increase at a lesser rate until the age of 90 days. It is noted that the 10% replacement ratio has a dry density higher than the density of the control cement samples. With the increase in the replacement ratio, the dry bulk density begins to decrease under the control cement sample.

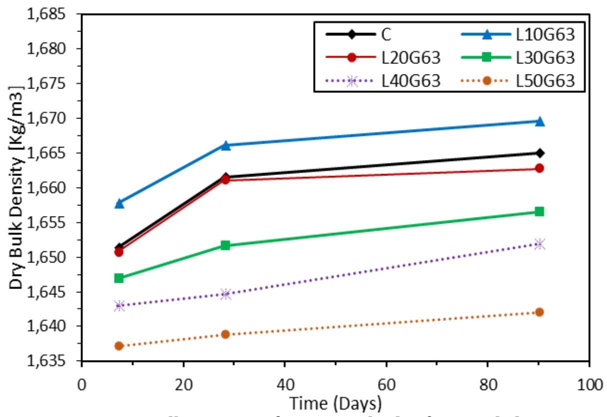

Figure 11. Dry Bulk Density of motor with ultrafine steel slag power

For all replacement samples, the total porosity decreases with the age of 28 days very significantly and then begins to decrease at a lower rate until the age of 90 days. It is noted that the 10% replacement ratio improves the properties of the solid mortar, as it has a porosity less than the porosity of the control cement samples, and with the increase in the replacement ratio, the porosity rises above the control cement sample. Figure 12 shows the Total Porosity of motor with ultrafine steel slag power

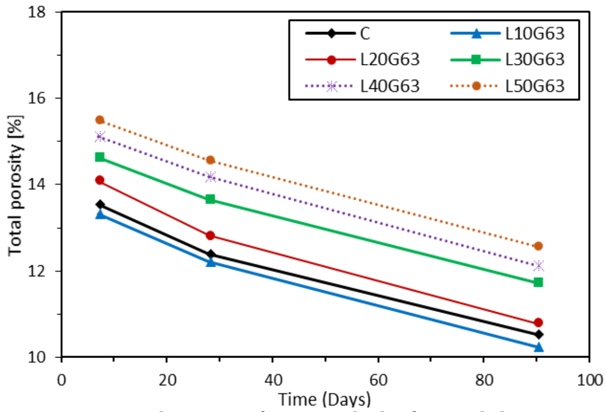

Figure 12. Total Porosity of motor with ultrafine steel slag power

The Water Absorption Capacity is related with the porosity and the dry bulk density, and it is noted that with the increase in the replacement ratio, the Water Absorption Capacity increases for all ages, as shown in the figure 13.

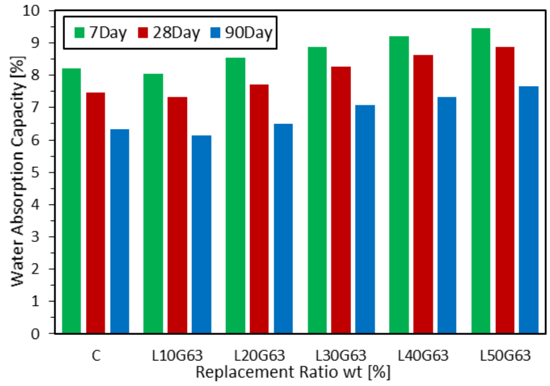

Figure 13. Water absorption Capacity of motor with ultrafine steel slag power

Compressive strength, Flexural strength and Activity index

The compressive strength of slag steel powder with cement slurry was much lower. At the age of 28 days, the cementitious part of slag steel powder was more inert than Portland cement, so the slag steel powder is only subject to very small chemical influence. However, the compressive strength of 56 days L10G63 cement mortar (59.45 MPa) increased rapidly. This is maybe because the cementitious portion of the steel slag is increasingly contributing to strength development with increasing curing age. For all cement mortar samples, the compressive strength increased with increasing curing life as shown in Figure. 14.

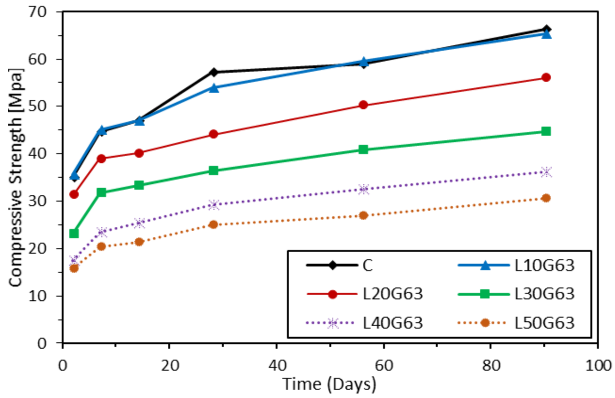

Figure 14. Compressive Strength of motor with ultrafine steel slag power

According to the results, the addition of ultrafine steel slag powder has a negative effect on the Flexural Strength of the blended cement. ultrafine Steel slag powder may safely replace up to 10% of the OPC but ultrafine steel slag powder reduces the mechanical properties of cement when the replacement ratio is increased. Figure 15 shows the Flexural Strength of motor with ultrafine steel slag power

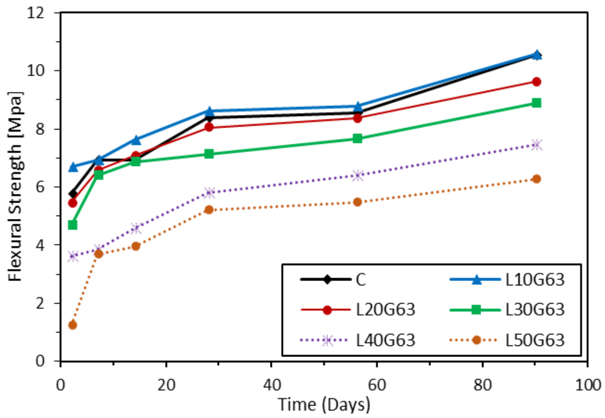

Figure 15. Flexural Strength of motor with s ultrafine teel slag power

Figure 16 shows the activity index of 2d, 7d, 14d, 28d, 56d and 90d of the mortar samples with different ultrafine Steel slag powder contents. The activity index of mortar decreased with the addition of ultrafine steel slag powder. It is clear that the activity index decreases significantly at the age of 28 days, but begins to improve at the ages of 56 and 90 days. It is worth noting that replacing high-strength cement with ultrafine steel slag powder may not give the desired results due to the sensitivity of the cement and its intensity of reaction compared to powdered steel slag.

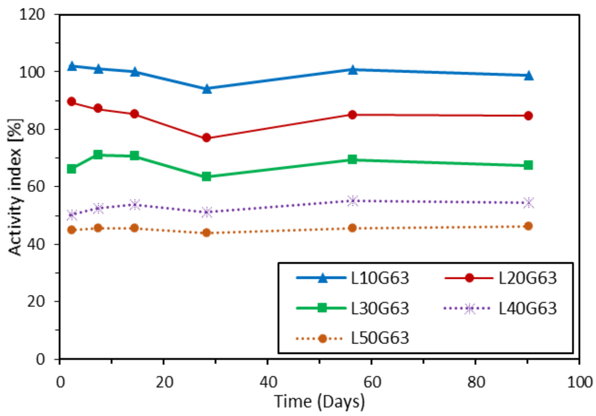

Figure 16. Activity index of mortars with ultrafine steel slag power

IV. CONCLUSION AND RECOMMENDATIONS

Steel Slag is generated as a by-product during iron- and steelmaking which result in considerable compositional and physical variability to various slags. To correctly and successfully use a particular ferrous slag mainly depends on the understanding of its chemical, mineral, and physical properties, and the technical requirements of the end products and utilization.

The results of the chemical analysis showed that the main oxides present in ultrafine steel slag powder are mostly similar to those in OPC. The activity of ultrafine steel slag powder was evaluated in cement mortars and the results showed that ultrafine steel slag powder had poor hydraulic activity at early ages, but became active after 56 days of curing.

The water requirement decreases at the replacement ratio of 10% and then becomes stable up to 20% and then begins to increase significantly as the steel slag powder becomes dominant over the mixture and due to its ultra-fineness, it requires more water than cement.

Both the initial setting time and final setting time were also accelerated than that of the control sample. The reason for this may be the amounts of water added to the mixture with each replacement ratio.

Due to the constant ratio of water to cement and steel slag powder (binder) the fluidity of the mortars without ultrafine steel slag powder is relatively low, and the bulk density without ultrafine steel slag powder is relatively high. However, the bulk density decreases with the cement replacement ratio.

For all replacement samples, the dry bulk density increases with the age of 28 days very significantly and then begins to increase at a lesser rate until the age of 90 days, and the total porosity decreases with the age of 28 days very significantly and then begins to decrease at a lower rate until the age of 90 days. The Water Absorption Capacity is related to the porosity and the dry bulk density, and it is noted that with the increase in the replacement ratio, the Water Absorption Capacity increases for all ages.

The compressive strength of the blended cement mortars was similar to that of OPC at 90 days. This means that it has good hydraulic activity and can safely replace a portion of the OPC in the blended mortar by no more than 10% and the Flexural strength of the mortar with steel slag powder shows encouraging results in later ages. steel slag powder may safely replace up to 10% of OPC but it reduces the mechanical properties of cement.

This study recommends conducting laboratory experiments on durability requirements, SEM and XRD analyzes and there is a need to study its effect on cement mortars with higher replacement ratios. New methods need to be developed so that comparable 28 days' strength could be achieved.

ACKNOWLEDGMENT

My special thanks and gratitude to my supervisor Prof. Dr. Hamza Ben Omran for his guidance and continuous support during my work. Many thanks to Engineer Faraj Al-Haddad, who helped me with his time, effort and knowledge in preparing this study. Many thanks to the Libyan Cement Company - Al-Fateeh Cement Factory, who sponsored this research and provided the laboratory for experiments.

REFER ENCE

[1] C.H. Yu, et al., Characterization of spatial impact of particles emitted from a cement mate-rial production facility on outdoor particle deposition in the surrounding community, J. Air Waste Manage. Assoc. 61 (10) (2011) 1015–1025.

[2] Libyan Ministry of Manufacture. Proposed Plan to Improve the Manufacture of Construction Materials During the Period 1993 to 2000. Industrial Research Centre.

[3] Libyan Iron and Steel Company. Technical Specification of Products, Quality Control Department, Musrata, Libya. (1998).

[4] European Standard "cement, Part 1: Composition, specifications and conformity criteria for common cements." BS EN 197-1, European Committee for Standardization CEN, Brussels, September,2011.

[5] British Standard "*Specifications for Ground Granulated Blastfurnace Slag for use with Portland cement.*" BS 6699: 1992.

[6] European Standard "*Methods of testing cement, Part 2: Chemical analysis of cement*." BS EN 196-2, European Committee for Standardization CEN, Brussels, January,2013.

[7] European Standard "*Methods of testing cement, Part 3: Determination of setting times and soundness*." BS EN 196-3, European Committee for Standardization CEN, Brussels, November,2016.

[8] European Standard "*Methods of test for mortar for masonry, Part 3: Determination of consistence of fresh mortar (by flow table).*" BS EN 1015-3, European Committee for Standardization CEN, Brussels, February,1999.

[9] European Standard "*Methods of test for mortar for masonry, Part 6: Determination of bulk density of fresh mortar.*" BS EN 1015-6, European Committee for Standardization CEN, Brussels, October,1999.

[10] European Standard "*Methods of test for mortar for masonry, Part 10: Determination of dry bulk density of hardened mortar*." BS EN 1015-10, European Committee for Standardization CEN, Brussels, August,1999.

[11] American Society for Testing and Materials, "*Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*.", ASTM C 642-97, Annual Book of ASTM Standards, 2002

[12] European Standard *"Methods of test for mortar for masonry, Part 11: Determination of flexural and compressive strength of hardened mortar*." BS EN 1015-11, European Committee for Standardization CEN, Brussels, September,2019.