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Technical Note

USE OF BILLET SCALE AS PARTIAL REPLACEMENT OF SAND IN CONCRETE

S. Naganathan*, J.A Musazay
[1]Department of Civil Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000, Kajang, Selangor, Malaysia.
*Corresponding author. Email: sivaN@uniten.edu.my

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ABSTRACT

This paper presents the results of an investigation done on the use of steel billet scale as partial replacement of sand in concrete. Concrete mixtures were made with various percentages of replacement of billet scale in lieu of sand. Tests were conducted on fresh concrete for slump and fresh density and on hardened concrete for compressive strength, ultrasonic pulse velocity (UPV), rebound number, and for durability of concrete by immersion in saline medium. It was found out that the concrete up to 15% replacement level of billet scale showed increase in performance than the control mixture. The concrete strength reduced relatively for those samples cured in saline medium, but the 15% replacement was still the optimum replacement proportion. Replacement level of less than 15% and as well as more than 15 % showed decrement in strength.

Keywords: Billet scale; concrete; strength; durability; UPV.

1. INTRODUCTION

Billet scale is an industrial solid waste and hence it constitutes harm to environment. Its efficient replacement in concrete will not only help in introducing a new recyclable alternative for sand–which this in turn will result in reduction of natural materials depletion –but also contributes to sustainability in construction. Rapid depletion of natural resources and gradual accumulation of solid waste around the world are both considered significantly increasing environmental threats [1]. This fact has lead mankind to search for solutions not only to reduce the consumption of natural resources, especially those materials that cannot

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* E-mail address of the corresponding author: sivaN@uniten.edu.my (S. Naganathan)

be replenished, but also to recycle and reuse the used and consumed resources in order to curb both resources depletion and solid waste accumulation in one go.

Conventionally, waste materials are either burnt in incinerators, buried in landfills or composted. However, there are waste materials that are not suitable for any of the above mentioned solutions. For example, metals, plastics and glass are the common types of these materials. Steel billet scale is also from these materials. It cannot be incinerated and it cannot be composted. The left option is burying it in the landfills, but landfilling of steel billet scale is harmful to land and eventually to environment.

Hence, the only way to make use of billet scale or to get rid of it is to recycle it. Recycling is a logical option for materials not suitable for composting [2].

2. LITERATURE REVIEW

As long as recycling of solid waste in concrete is concerned, a large amount of research has been carried out in the past and a similar amount is in progress around the globe. Replacing concrete's ingredients with solid waste fully or partially, have been a matter of interest for researchers and academicians in the past decades. The most attractive mechanical property of concrete, with no doubt, is its compressive strength. Therefore, establishing relationship between concrete's main components and its compressive strength is necessary. In fact, relationship between concrete compositions and its compressive strength has long been a matter of interest for researchers [3].

In a study for partial replacement of fine aggregate with steel billet scales, Akindahunsi, used six different mixing proportions including the control concrete, namely 0%, 15%, 30%, 45%, 60%, and 75%. It was found out that for a concrete of Grade 25 at 28 days of curing, the compressive strength of his specimens were higher than that of the control concrete in 15% of replacement of fine aggregate with billet scales. Therefore, 15% was reported as optimum content for replacing fine aggregate with steel billet scales. It was also stated, however, that the other replacement proportions could also be used efficiently in mass concrete works where the required concrete grade is $15N/mm^2$ [4].

Mohamed Alwaeli and Jan Nadziakiewicz investigated the effect of recycling of steel scales and chips in concrete as sand replacement. Four different proportions of 25%, 50%, 75% and 100%. In the findings about compressive strength, the data showed that the concrete mixed with steel chips have better strength than conventional concrete, while in the case of concrete mixed with scale in excess of 25%, the strength become deteriorated [5].

Saud AL-Otaibi studied the effect of recycling steel mill scales as a replacement for fine aggregate in cement mortars. It was found out that replacing 40% of steel mill scales with sand is the optimum content for cement mortars in terms of compressive strength. It was also stated that in the same proportion replacement, e.g. 40%, flexural strength of concrete increased as well [6].

Zainab Z. Ismail and Enas A. AL-Hashmi investigate the effect of reusing of waste iron as a partial replacement of sand in concrete. Three different proportions of 10%, 15% and 20% and cured the specimens for ages of 3, 7, 14, and 28 days. It was found out that, the concrete mixes made with waste iron had higher compressive strengths and flexural strengths than the plain concrete mixes [2].

Beside strength, other properties of concrete were also investigated during this study, e.g. slump magnitude, fresh density, rebound hummer and ultrasonic pulse velocity or UPV. However, research on relating these mentioned properties of concrete in a concrete sample which its fine aggregate is partially replaced with billet scales, is still very limited. Nevertheless, there is a huge number of research relating UPV with compressive strength, be it conventional concrete or other types of concretes whereby one of its principle ingredients, especially fine aggregate, is replaced partially or fully with other solid wastes.

In an investigation to correlate the concrete compressive strength with ultrasonic pulse velocity, Guang Ye, K. Van Breugel and A.L.A.Fraaij found out that the UPV in concrete increases as concrete's compressive strength increases. As it is stated in this respective findings, the relationship between concrete's compressive strength is almost linear at early ages, but as the time progresses, the ultrasonic pulse velocity tends to become constant [7].

Ramazan Demirbog˘a, I˙brahim Tu¨rkmen and Mehmet B. Karakoc investigated the relationship between concrete compressive strength and UPV. High-volume mineral-admixture concrete was used in this respective. It was found out that the compressive strength and UPV of the samples were low at early ages, but increased by time. In the other words, UPV increased as the compressive strength increased [8].

In another study, Gregor Trtnik, Franci Kavc ic and Goran Turk also found out that concrete compressive strength is directly proportional to its ultrasonic pulse velocity in the early stages of concrete, but tends to get constant as the time progresses [9].

For this investigation, concrete mixtures of various percentages of partial replacement of billet scale in lieu of sand such as 0% (control concrete), 5%, 10%, 15%, 20%, 25% will be used. For hardened concrete, compressive strength, ultrasonic pulse velocity (UPV) and rebound number tests for different ages such as 3, 14 and 28 days will be conducted. For durability of concrete, samples will be immersed in saline medium and will be tested for same properties at the same ages accordingly. Beside these, concrete's fresh properties such as slump magnitude and fresh density, ingredients' properties such as fine and course aggregates and billet scale's specific gravity, water absorption, grading curves and chemical composition of billet scale will be determined.

3. MATERIALS AND METHODS

3.1 Materials

Principle materials used for preparation of specimens for testing for this investigation were water, cement, coarse aggregate, fine aggregate, billet scale and sodium chloride (for preparation of saline water). Fresh water confirming to SYABAS potable water standards was used for concrete mixing with a w/c ratio of 0.56. Ordinary Portland Cement (OPC) confirming to MS 522: Part 1: 2007 was used to prepare the specimens. The coarse aggregate used for this project was crushed granite with nominal coarse aggregate size of 20mm. The sand that was used for this study was river sand with nominal fine aggregate size of 3mm. Billet scale for this study was sourced from one of the local steel processing factories, Amsteel Mills Sdn. Bhd. at Lot 1, Jalan Waja, Bukit Raja Industrial Estate, 41050

Klang, Selangor Darul Ehsan, Malaysia. Properties of the materials are shown in Table 1. Chemical composition of billet scale and cement are shown in Table 2. Particle size distribution or grading curves of coarse aggregate, fine aggregate and billet scale are shown Figure 1 and 2, respectively.

Particle sizes and shape tests (sieve analysis) for the three materials were carried out based on BS 812: Part 1: 1975 [17]. Specific gravity and water absorption for coarse aggregate were carried out in accordance with ASTM C 127 [18] and those of fine aggregate and billet scale were carried out following ASTM C 128 [19]. Billet scale was also tested as fine aggregate, because the intended use of billet scale for this investigation is to be replaced with fine aggregate partially.

Table 1: Properties of the materials used for this investigation

	Apparent Specific Gravity	Water Absorption (%)
Coarse Aggregate	2.84	2.78
Fine Aggregate	2.72	0.46
Billet Scale	2.97	1.32

Table 2: Chemical composition of billet scale and cement

Name	Symbol	Billet Scale (%)	Cement (%)
Iron (lll) oxide	Fe_2O_3	96.900	3.640
Silicon Dioxide	SiO_2	0.880	21.270
Calcium Oxide	CaO	0.650	65.200
Manganese (ll) Oxide	MnO	0.560	0.080
Aluminum Oxide	Al_2O_3	0.340	6.190
Sulfur Trioxide	SO_3	0.210	---
Magnesium Oxide	MgO	0.150	0.880
Copper (ll) Oxide	CuO	0.150	---
Chromium (lll) Oxide	Cr_2O_3	0.097	---
Nickel Oxide	NiO	0.046	---
Vanadium Oxide	V_2O_5	0.019	---
Zinc Oxide	ZnO	0.015	---
Molybdenum Trioxide	MoO_3	0.010	---
Potassium Oxide	K_2O	---	0.71
Titanium Dioxide	TiO_2	---	0.22
Sodium Oxide	Na_2O	---	0.19
Phosphorus Dioxide	P_2O_2	---	0.09
Loss on Ignition	LOI	---	1.53

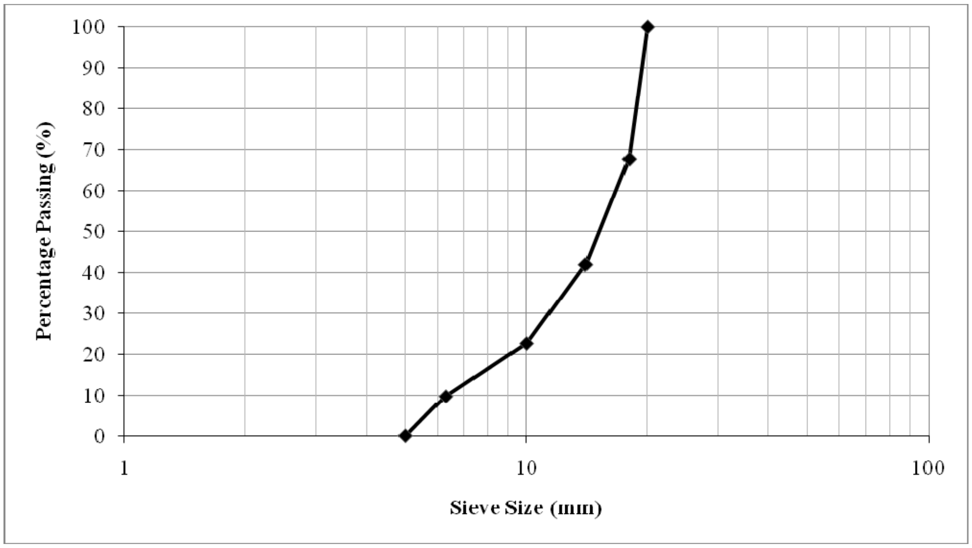


Figure 1. Grading curve for coarse aggregate used for this investigation

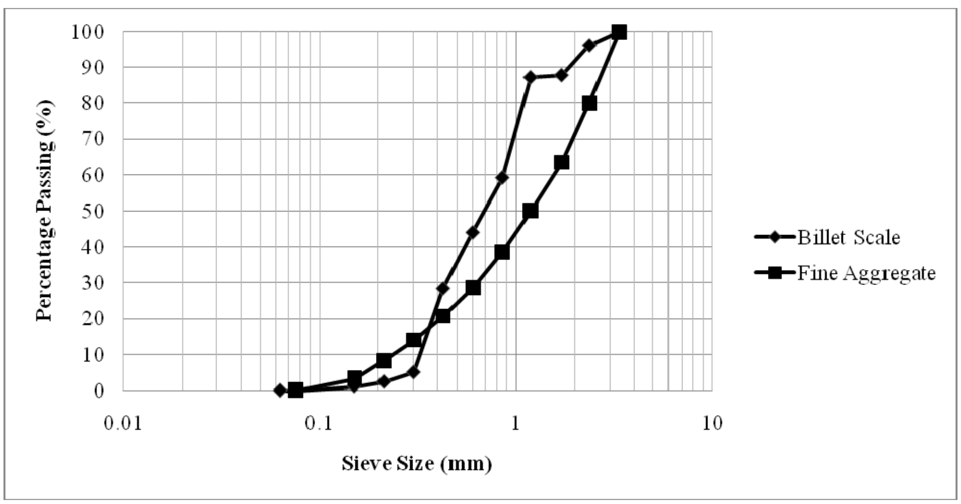


Figure 2. Combined grading curves for fine aggregate and billet scale

3.2 Methods

In this study, steel billet scale was used as a partial replacement for fine aggregate in concrete. Six different batches of concrete were prepared. The replacement proportions were 0% (the control concrete), 5%, 10%, 15%, 20% and 25% and curing ages were 3, 14 and 28 days. The specimens were cured for the above 3 different ages in fresh water and as well as in water contaminated with dissolved sodium chloride (NaCl). To simulate saline water, the amount of sodium chloride that was added to fresh water was 5% by weight of the water.

Grade 30 concrete was designed for this investigation and specimens of 100mm x 100mm x 100mm were prepared. Fresh concrete was designed based on DoE Method. Before preparing specimens, in fresh state of concrete, slump test and fresh density test for each batch of concrete was carried out in accordance with BS 1881: Part 102: 1983 [10] and BS 1881: Part 107: 1983 [11] respectively.

It should be noted that, there was a modification in the diameter of the equipment for the fresh density test. The diameter of the equipment used for fresh density test under this study was 155mm and it is height was 300mm. Test cubes were made from fresh concrete based on BS 1881: Part 108: 1983 [12]. However, the mixing was hand mixed because each 3 concrete cubes were made from different concrete batch and hence the volume of concrete for each testing batch (3 cubes) were relatively small to use mixing machine. The cubes were cured following BS 1881: Part 111: 1983 [13].

Likewise, in hardened state, they were tested for compressive strength based on BS 1881: Part 116: 1983 [14], for rebound hammer BS 1881: Part 202: 1986 [15] and for ultrasonic pulse velocity in accordance with BS 1881: Part 203: 1986 [16].

3.3 Mix Design and Mix Proportion

The mix design and mix proportions are indicated in Table 3. Mix design is based on DoE Method of concrete mixing. The materials were mixed thoroughly in dry state by hand and as well as use of necessary tools such as spade, scoop, tray and etc. When the mix was ready in its dry state, water was added at the last and then mixed again.

Table 3: Mix design and proportions

Batch No	**Proportion (%)**	**Composition (kg/m³)**					**Fresh Density (kg/m³)**
		BS	**FA**	**CA**	**Cement**	**Water**	
1	0	0.0	817	998	375	210	2375.654
2	5	41	776	998	375	210	2383.427
3	10	82	735	998	375	210	2394.026
4	15	123	694	998	375	210	2403.565
5	20	163	654	998	375	210	2435.717
6	25	204	613	998	375	210	2474.227

Note: BS is billet scale, FA is Fine aggregate and CA is coarse aggregate.

4. RESULTS AND DISCUSSION

4.1 Fresh density and slump

The results of the investigation done on concrete mixture are presented and discussed in this section. The fresh properties of concrete mixtures are shown in Table 4 and compressive strength of concrete is given in Table 5. The relationship between slump value and fresh density with percentage replacement are shown in Figure 3 and 4 respectively. Relationship between compressive strength and sand percentage replacement is shown in Figure 5.

Table 4: Slump magnitude and density of fresh concrete

Replacement proportion (%)	Slump Magnitude (mm)	Fresh Density (kg/m3)
0	33	2375.7
5	34	2383.4
10	36	2394.0
15	40	2403.6
20	46	2435.7
25	56	2474.2

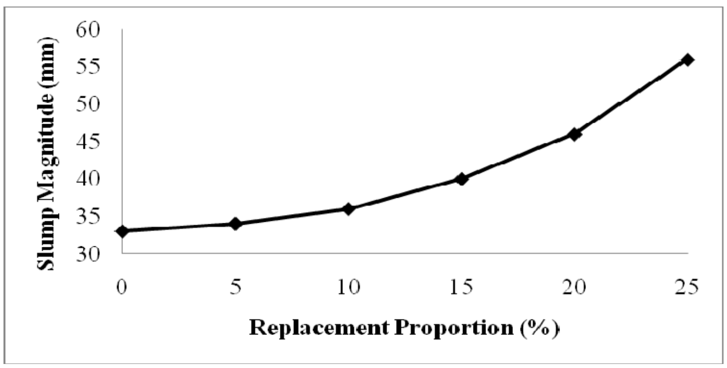


Figure 3. Relationship between slump magnitude and sand replacement percentage

As it can be noticed in Figure 3, the slump magnitude is increasing as the sand replacement proportion increases. This is probably because the billet scales particles are finer than sand and hence these fine particles increase workability of concrete. Therefore, when the workability increases, the slump magnitude increases as well.

In an almost similar manner, as it can be seen in Figure 4, the fresh density of the concrete also increases as the percentage replacement of billet scale increases in the mix. As it can be noted, initially this increment is almost linear, but right after 15% replacement, there is a leap in fresh density. This is because the billet scale particles were smaller than the sand particles and, geometrically, billet scale particles are tiny flaky surfaces compare to sand which is rounded in shape.

This difference causes a slight reduction in volume and therefore, since the volume of the material is reduced by replacing sand with billet scales, more of the prepared mix will be needed to fill the same cylinder fully during the fresh density test. This in return, increases the mass of the compacted mix inside the cylinder and hence any increase in the weight, increases the fresh density since the volume of the cylinder is constant. Although sand is replaced with billet scale by same weight, but sand particles of same mass occupies more space (volume) compare to billet scale particles of same mass. Therefore, this fact increases density of fresh concrete.

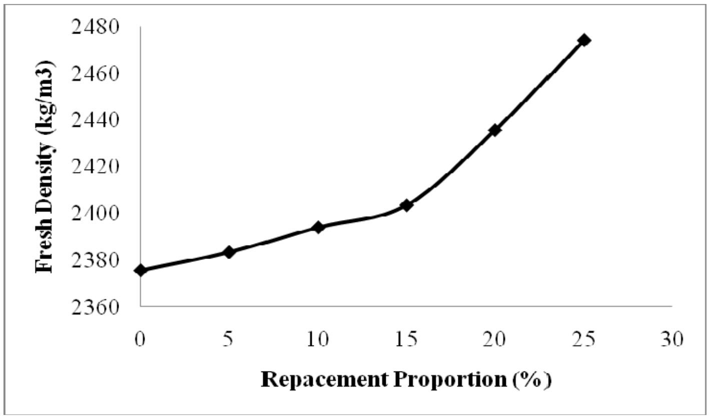


Figure 4. Relationship between fresh density and sand replacement percentage

4.2 Compressive strength

Table 5: Compressive strength specimens recorded under this study

Curing Age (Days)	Test Records (Reading)	Fine Aggregate Replacement Percentage (%)					
		0	**5**	**10**	**15**	**20**	**25**
		Compressive Strength (MPa)					
3	**Average**	**20.11**	**19.27**	**18.11**	**21.75**	**20.98**	**18.25**
14		**27.33**	**26.62**	**26.22**	**30.02**	**28.27**	**27.09**
28		**31.20**	**29.98**	**27.49**	**37.46**	**35.25**	**32.79**

From Figure 5, it can be observed that 15% replacement of sand with billet scale is the optimum replacement percentage. These samples were cured for different ages, e.g. 3, 14 and 28 days in fresh water. As it can be noticed, irrespective of curing age and curing medium, samples having 15% sand replaced with billet scale peaked in compressive strength as it can be seen both in Table 5 and Figure 5. At this certain replacement percentage, the testing specimens' compressive strength was higher than that of the control specimens. Specimens' strength development graphs are presented in Figure 6 and the data for this is presented in Table 6. From Figure 6 and Table 6, it can be noticed that development of compressive strength of this concrete samples are not constant initially, but it becomes constant for 14 and 28 days of curing. And as the time progress, the control concrete and concrete with 15% replacement keeps on increasing while the other samples' strength to tend to increase less, relatively.

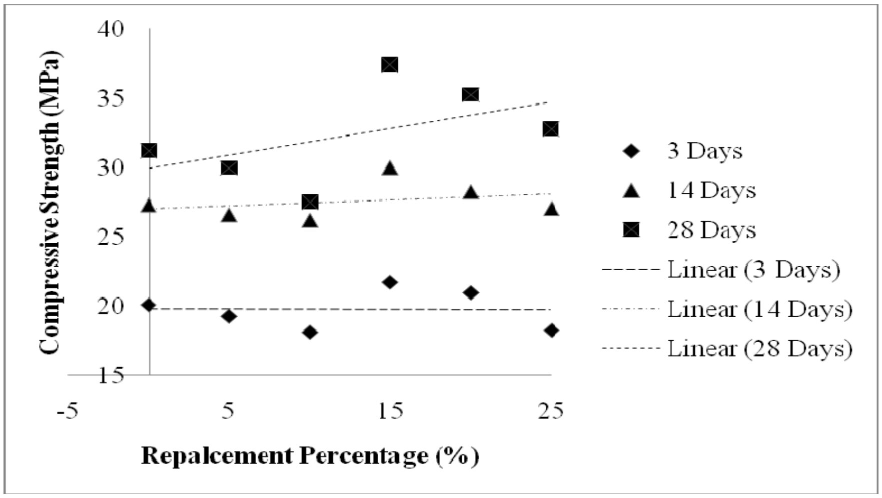


Figure 5. Relationship between compressive strength and sand replacement percentage for different ages according to Table 5 (fresh water curing)

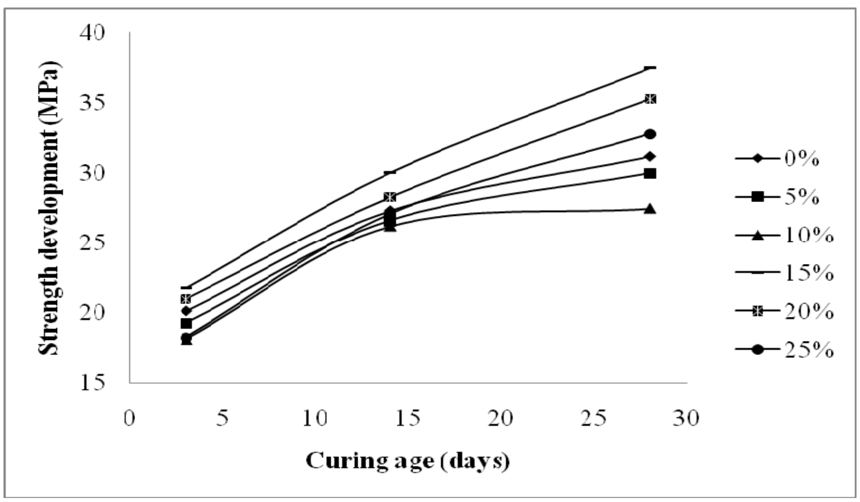


Figure 6. Relationship between compressive strength and time

Table 6: Strength development over time for different mixtures

	Replacement Proportion (%)					
	0	5	10	15	20	25
Curing Age (Days)	Compressive Strength (MPa)					
3	20.11	19.27	18.11	21.75	20.98	18.25
14	27.33	26.62	26.22	30.02	28.27	27.09
28	31.2	29.98	27.49	37.46	35.25	32.79

4.3 UPV and Rebound hammer

The concrete cubes were also tested for ultrasonic pulse velocity (UPV) by PUNDIT apparatus and surface hardness by a rebound hammer. It was found out that UPV decrement or increment is related to the concrete's compressive strength and concrete's age. It is not very much affected by proportion replacement of billet scale. However, 15% replacement of billet scale still remains as the optimum content. Figure 7 and 8 indicate the relationship between UPV with percentage replacement and UPV with curing age respectively and Figure 9 shows relationship between rebound numbers of the specimens with their percentage replacement.

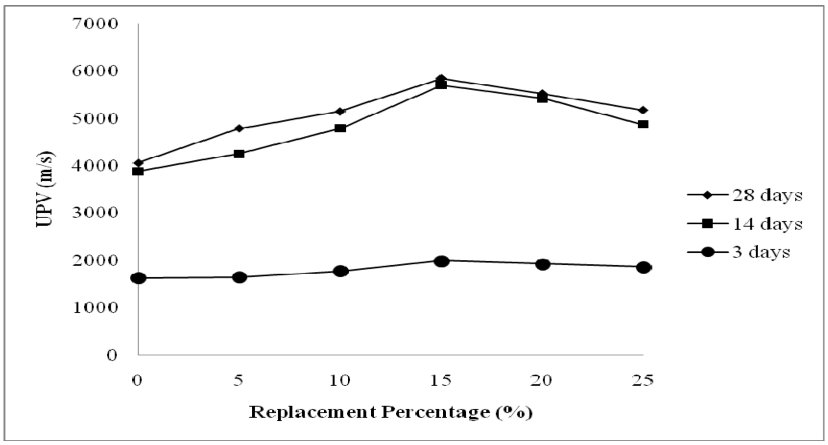


Figure 7. Relationship between UPV and replacement proportion

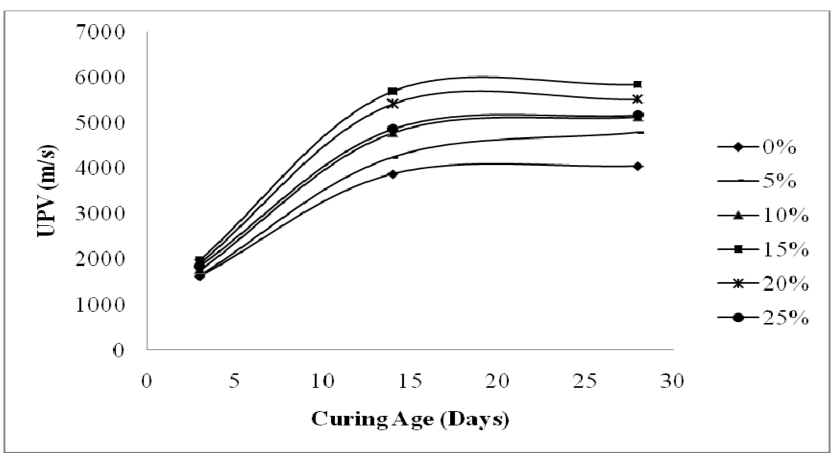


Figure 8. Relationship between UPV and curing age

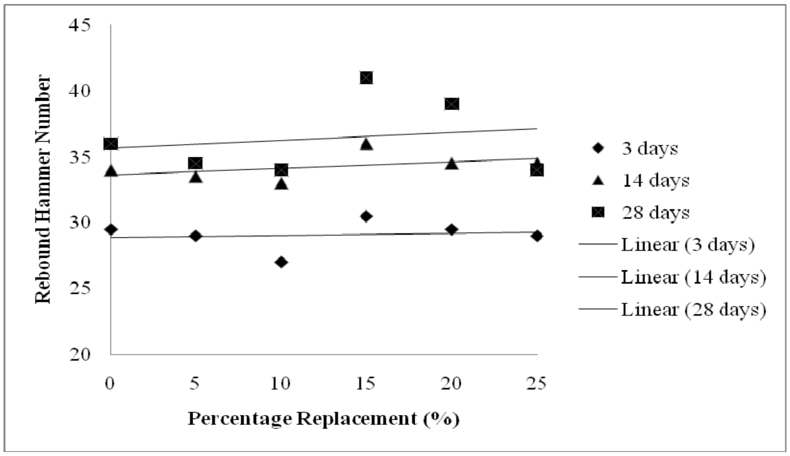


Figure 9. Relationship between rebound hammer number and replacement proportion

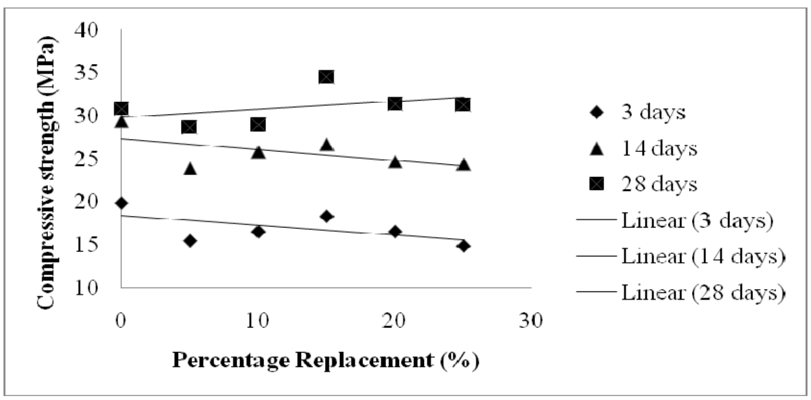


Figure 10. Relationship between compressive strength and percentage replacement (saline water curing)

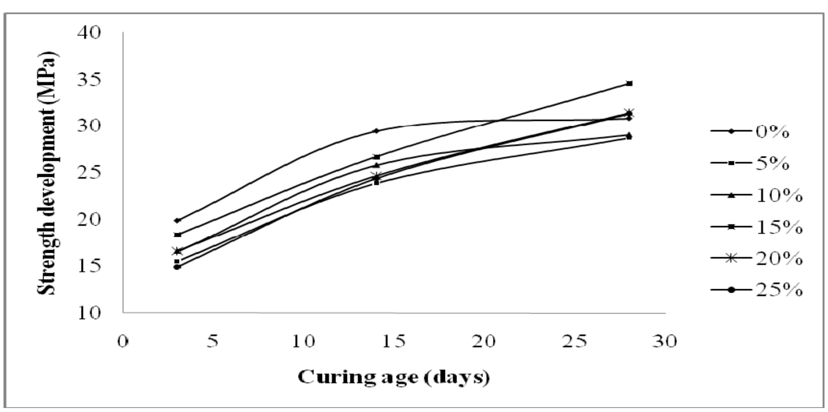


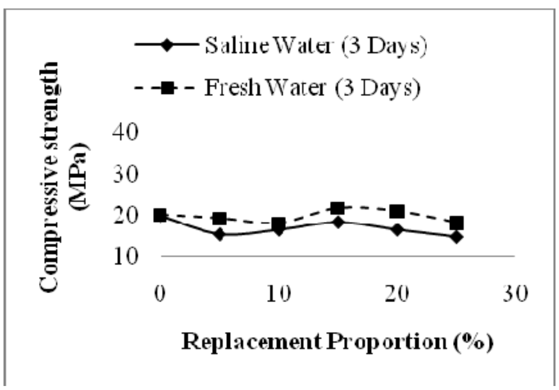
Figure 11. Relationship between compressive strength development and curing age (saline water curing)

4.4 Durability

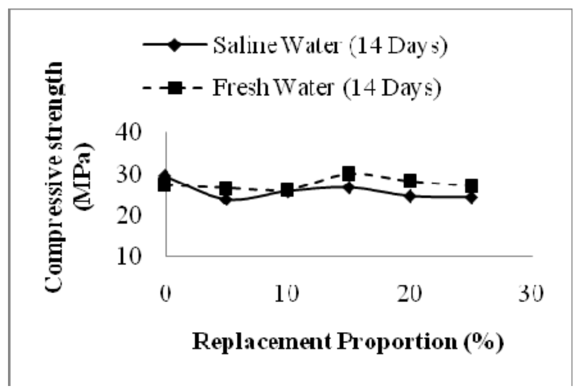
Specimens were also tested for durability under this investigation. For durability of concrete, specimens were immersed in saline medium and were cured for 3, 14 and 28 days. Likewise, these specimens were also tested for the same properties as of normal curing. Saline medium was prepared by adding 5% sodium chloride in fresh water by weight of water. For durability purposes, the different in properties of specimens cured in fresh water and specimens cured in saline water are compared. The justifications and visuals are presented in the following paragraphs and figures.

It can be observed from Figure 10 and 11 that strength of concrete is not very much affected by curing in saline water in the early ages, but as the time progresses the strength is reduced marginally. For example, at 28 days of curing in saline water, strength of the concrete specimens is reduced at least by 4.48%. This is because, as the age increase the effect of salt crystallization damage on the concrete increases as well [20].

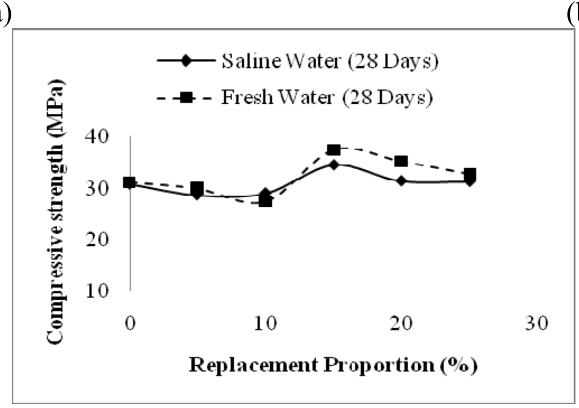
Besides, it was also found out by İbrahim Türkmem [21] and 400 days of curing that, curing of concrete specimens in saline water and having one of its ingredient replaced with a solid waste, decreases the compressive strength of the concrete as age of the concrete increases.



(a)



(b)

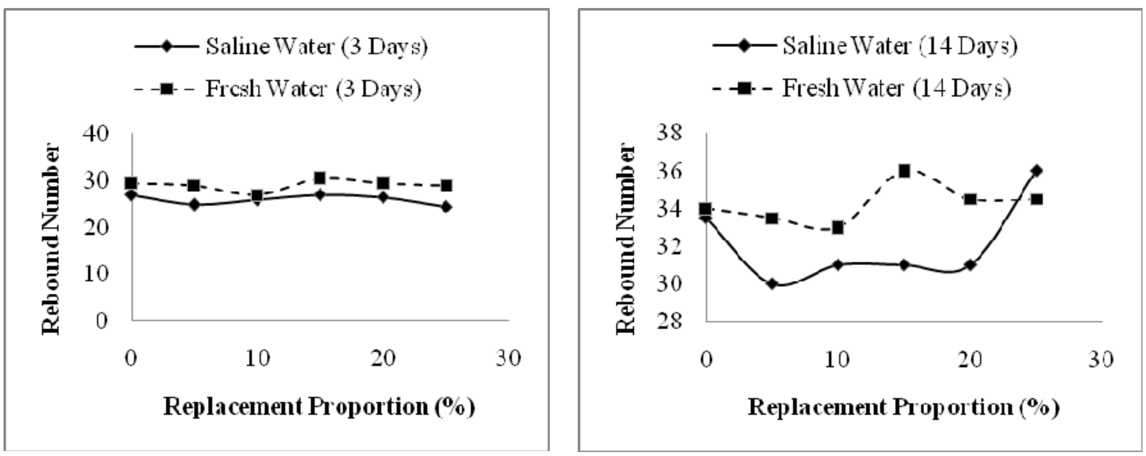


(c)

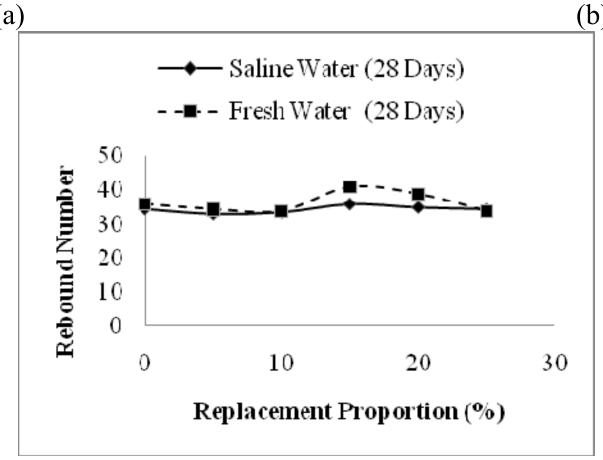
Figure 12. Relationship between compressive strength and replacement percentage for curing in fresh water and saline water for 3 (a), 14 (b) and 28 days of curing (c)

It should also be noted that regardless of the curing medium, the optimum content of billet scale to be replaced with fine aggregate is still 15%. For example, at 28 days of curing in saline medium and 15% of billet scale replaced with fine aggregate, the concrete specimens still had an average compressive strength value of 34.56MPa. The compressive strength of the control sample at this certain configuration was 30.83MPa. That is almost 11% increment. It is worth mentioning that the designed grade of the concrete used was 30MPa.

The data for ultrasonic pulse velocity of the concrete is not very dependent on the replacement proportion of billet scale with sand, but on strength. Pulse velocity of the samples cured in fresh water is higher compare to those cured in saline water. In general regarding ultrasonic pulse velocity, it can be noticed that the concrete batch with higher strength has also a higher UPV value. However, as the specimens' age progressed, UPV tended to became constant. This fact was almost similar for both fresh-water-cured and saline-water-cured concrete samples.



(a) (b)



(c)

Figure 14. Relationship between rebound number and replacement percentage for curing in fresh water and saline water for 3 days curing (a), 14 days curing (b) and 28 days curing (c)

As it can be noticed from Figure 14, surface hardness of the specimens measured by a rebound hammer is higher in fresh water curing compare to saline water curing. This is because of the salt crystallization damage on or near the surface of the specimens where drying takes place. When solutions of salts move through concrete, it increases the water evaporation rate in the concrete and this return tampers the hydration process [20].

5. CONCLUSIONS

For fresh concrete, it was found out that as the billet scale percentage replacement with sand increased, the slump magnitude increased too. Billet scale particles are finer than sand particles and this fact increased the workability of the concrete and hence as the workability increased, slump increased too.

Fresh density of the concrete increased as well as billet scale percentage replacement increased. This is also because of the particle size of billet scale. Since billet scale particles are finer, more of them can be accommodated into the same volume compare to sand particles, hence increasing fresh density.

Irrespective of curing age and curing medium, it was found out that 15% replacement of billet scales with fine aggregate in concrete is the optimum content for structural purposes. In this certain proportional percentage, (15%), it was found out that, not only the strength didn't reduce, but increased compare to concrete with 0% replacement or control concrete. other percentage replacement of billet scales with fine aggregate, e.g. 5%, 10%, 20% and 25% can be used for non-structural purposes where mass concrete is used.

Ultrasonic pulse velocity of the concrete is not really dependent on the replacement proportion of billet scale with sand, but on strength. It was found out the, the concrete batch with higher strength has also a higher UPV value. However, as the specimens' age progressed, UPV tended to became constant. This fact was almost similar for both fresh-water-cured and saline-water-cured concrete samples.

Surface hardness of the specimens, tested by a rebound hammer was higher for those cubes cured in fresh water compare to those cubes cured in saline water.

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