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REUSE OF WATEWATER FROM THE STONE INDUSTRY IN PRODUCTION OF CAST STONE

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Abstract

This research presents an attempt of using wastewater from slurry waste of stone cutting plants in production of cast stone. Several mixes that can be used in producing cast stone were prepared by using tap water and stone slurry wastewater at different replacement ratios of wastewater in substitute of tap water. Different samples were tested to measure the slump of fresh cast stone mix and compressive strength and absorption of hardened cast stone samples. Two water cement ratios were used 0.6 and 0.7 and four different percentages of replaced water were used 0%, 20%, and 100% for each w/c ratio.
The revealed results of the tested samples showed that although the slump of fresh mixes was reduced, the compressive strength of the hardened samples was not affected much. The absorption increased by using slurry wastewater at different ratios. The expected outcome of this research is reduction of using tap water in producing cast stone. Substantial amount of fresh water consumed by the growing cast stone industry in Palestine will be conserved for domestic use.

Keywords: Stone Slurry, Reuse, Wastewater, Cast stones

1. Introduction

The most important profession in Palestine is the production of building stone. There are about 400 stone quarries, the source of building stones, and more than 1000 stone cutting facilities are situated across the West Bank and Gaza. The stone and marble sector is having the largest percentage of employment of Palestinian labour force with more than 13500 workers. The annual Palestinian production of finished stone and marble is more than 16 million square meters, equals to more than 1.6 million tons. The stone and marble sector contributes approximately 25% of Palestine's overall industrial revenue and 4.5% to the total Palestinian GNP. The total annual revenue of this industry is estimated at $450 million. (USM, 2011)Spreading of stone quarries in many areas is disturbing the beautiful nature of land and destroys large cultivated areas. Figure 1. shows the effect of stone quarrying on nature.

Figure 1. A view for a stone quarry showing the effect of quarrying on nature

Clearly, the potential of the stone industry is very large. However, in order to realize these potential gains, many problems and challenges on the national and industry level remain to be addressed. The process starts with quarrying rocks from quarries and transporting them to the stone cutting facility. In all stone cutting facilities the rocks are cut and shaped. Water is primarily used as a cooling, lubricating and cleaning agent for preventing dust generation during the sawing and polishing processes. Therefore, the stone cutting industry is considered to be the largest consumer of fresh water and producer of wastewater and solid waste in the West Bank, and of air-born pollutants. The stone slurry waste is a viscous material resulted from sawing, shaping and polishing process. It contains approximately 65% of water. The stone slurry is usually disposed in open areas causing many health problems, land contamination and sewerage network blockage. Many attempts have been made locally and worldwide to solve the stone slurry waste problem by using it in its viscous state or after drying. Many attempts were made to recycle the stone slurry waste in production of construction materials. Figure 2. shows the use of water as a lubricant in the stone cutting and processing in one of the stone cutting plants.

Figure 2. The use of water as a lubricator in the stone cutting process

In last two decades, cast stone industry has developed in Palestine to minimize the effect of stone quarrying on nature, to minimize the environmental effects of wastewater slurry resulting from stone cutting plants and to decrease the rate of producing natural stone saving this important natural resource for future. More than 100 cast stone plants are now in Palestine producing different types of cast stone products.

This research is an attempt to use the wastewater from stone slurry waste in partially replacement of fresh water in production of cast stone. Similar research has been conducted by the authors to investigate the potential use of wastewater from stone slurry waste in partial replacement of fresh water in production of concrete. The compressive strength, absorption of hardened cast stone were tested along with slump of fresh mix. Using amounts of the stone slurry wastewater in cast stone production may save large amounts of fresh water annually, for domestic use in Palestine. Figure 3. shows the discharge of stone slurry wastewater from stone cutting plant out into an open areas.

Figure 3. Discharge of stone slurry wastewater from stone cutting plant out in open areas

2. Literature Review

Due to increasing human population and scarce water recourses, coupled with environmental impact of wastewater resulting from different industrial activities, many researchers all over the world started to think of partial replacement of tap water by treated wastewater. Based on experimental work to examine the effect of partial replacement of drinkable water used in concrete mixes by treated wastewater on the properties of produced concrete it has been concluded that the idea of using waste water from stone industry is feasible.

Al-Joulani and Awad (2019) studied the effect of partial replacement of tap water by wastewater from stone cutting plants on the properties of fresh and hardened concrete. They concluded that the slump of fresh concrete was reduced while the compressive strength of hardened concrete was not affected much by the partial replacement of fresh water.

G.Reddy Babu et. al. (2018) published a review on the quality of mixing water in concrete. In their study they emphasized the possibility of using non-traditional water in concrete referring to existing broad standards available in various codes of mixing water for concrete. They concluded that some of non-traditional water may be used safely in concrete mixtures.

Aeslina Abdul Kadir et al. (2016) studied the effect of slurry water as a fresh water replacement in concrete properties. The results of the study revealed that, the concrete with 20% replacement of slurry water achieved the higher compressive strength compared to other percentages.

Kucche, M.K et. al. (2015), reported a literature review of the quality of water for making concrete. The authors compiled the allowable limits of physical and chemical impurities and their test methods from different countries standards. The authors concluded that the reaction between water and cement affect the setting time, compressive strength and also lead to softening of concrete.

Al-Joulani N. (2014), presented results about the utilization of stone slurry waste in production of artificial stones. The results indicated that the stone slurry waste could be used in producing artificial stones with reasonable compressive strength and natural absorption compared with natural stones.

ATA Olugbenga (2014), studied the effects of water from different sources on concrete strength due to scarcity of water in Nigeria. He investigated the effect of different types of water on the compressive strength of concrete. The authors also, studied the effect of the presence of some impurities like silt and suspended particles on the strength of concrete. The study concluded that the sources of water have a significant impact on the properties of concrete.

Bassam Mahasneh (2014) conducted experimental study to evaluate the effect of using treated wastewater on the properties of concrete in comparison with concrete made with tap water. He concluded that that there was an average reduction of 7.3% in the compressive strength of concrete cube samples prepared using treated wastewater, however this complies with British Standards and AASHTO standards which require that compressive strength of cubes made of waste water not be less than 90% of the compressive strength of cubes made of tap water.

K. S. Al-Jabri et al. (2011) investigated the effect of using wastewater on the properties of high strength concrete. Chemical analysis results showed that although the chemical composition of the wastewater were much higher than the tap water parameters, the water composition was within the ASTM standard limits for all substances indicating that the produced wastewater can be used satisfactorily in concrete mixes. The percentage of wastewater replaced changed between 25%-100% of tap water used in concrete. Results indicated that the strength of concrete of the mixtures prepared using wastewater was comparable to the strength of control mix.

Rakesh A. More et al. (2014) investigated the effect of different types of water on the compressive strength of concrete. The results showed that while the compressive strength of the concrete cubes increased by time not much variation in strength was noticed by using the different types of used water: mineral water, tap water, well water and wastewater.

3. Objectives

This study focuses on the reuse of wastewater from the stone-slurry waste in production of cast stone, the specific objectives of the study are:

- To investigate the opportunity of beneficial reuse of industrial liquid waste in concrete industry.
- To participate in the efforts for minimizing the environmental impact of wastewater resulting from stone cutting industry in Palestine.
- And to encourage the production of cast stone to partially replace the consumption of natural stone.

Adoption and implementation of the research results will contribute to saving of a large amount of fresh water annually, protecting the environment from the industrial pollution, enhancement of public health and welfare and providing economic befits due to reduction in water consumption.

4. Methodology

In this study a number of steps that include data gathering and experimental work were followed:

1- A questionnaire was designed and distributed on a number of cast stone production plants to find out the amount of water consumed in cast stone industry and the source of this water.

2- Site visits and interviews were also conducted with owners and managers of cast stone plants in different governorates in Palestine.

3- Literature review and documentary analysis, was another tool for data collection. The targeted documents were: recycling related reports, regulations and bylaws….etc, and this tool provided the study with facts related to current practice in dealing with recycling of stone slurry waste in Palestine.

4- Samples of mixes used in producing cast stone were produced by different w/c ratios and replacement ratios of wastewater in substitute of fresh mixing water. The samples were cured and tested in An-Najah National University building materials labs.

5. Experimental Program

Preparation of different cast stone mixes in the building materials lab at An-Najah National University. The mixes were changed by using two different w/c ratios (0.6, and 0.7). The reference mix was made by using fresh water (potable water). Many other mixes with the same w/c ratio, were made using stone slurry wastewater in replacement of fresh water at different percentages. A total of 8 mixes were explored at different replacement ratios of wastewater (SW). The constituents of cast stone mixes, shown in Figure 4, are the white cement, coarse and fine aggregates. The constituent's ratios of the different cast stone mixes are shown in Table 1.

a) White Cement

b) Coarse aggregate

c) Fine aggregate

Figure 4. Constituents of cast stone mix

Table 1. Cast stone mixes constituents

Water Type , Replacement %, (w/c Ratio)	Portland cement type 1 (kg/m^3)	Water (kg/m3)	Sludge water (kg/m$^{3)}$	Fine Aggregate (Sand) (kg/m$^{3)}$	Coarse Aggregate (Crushed limestone) (kg/m^3)
SW 0 (0.6)	309	185	0	896	956
SW20 (0.6)	309	148	37	896	956
SW40 (0.6)	309	111	74	896	956
SW100 (0.6)	309	0	185	896	956
SW 0 (0.7)	279	195	0	896	956
SW20 (0.7)	279	156	39	896	956
SW40 (0.7)	279	117	78	910	966
SW100 (0.7)	279	0	195	910	966

SW: Stone slurry wastewater

A. Mixing water:

Since the mix used in producing cast stone is similar to concrete mix, the specifications of mixing water used in concrete can be adopted for water that can be used in mixing the compounds of cast stone. According to ASTM C94 specifications the appropriate water for mixing is potable water, the specifications (ASTM C94) usually stipulate that the water must be free of chloride, sulfate and salts and is also free from harmful substances such as oils, grease, acids, alkalis, organic matters, cork and other substances that have a reverse effect on concrete in terms of strength and durability. Three samples of stone slurry wastewater treated by sedimentation were tested. Table 2. shows the chemical properties of the stone slurry wastewater used in this research:

Table 2. Properties of stone slurry wastewater used in this research

Test	Units	Results	Ref
pH	--	7.98	SMWW
Turbidity	NTU	9.3	SMWW
NO3	Mg/L	50.92	SMWW
SO4	Mg/L	20.27	SMWW
Total Hardness as (CaCo3)	Mg/L	280	SMWW
Total Alkalinity as (CaCo3)	Mg/L	210	SMWW
TDS	Mg/L	433.5	SMWW
TSS	Mg/L	38	SMWW
Ca	Mg/L	48	SMWW
Mg	Mg/L	39	SMWW
Na	Mg/L	60.1	SMWW
K	Mg/L	8.3	SMWW
Al_2O_3	%	<0.001	SMWW
Fe_2O_3	%	0.003	SMWW
CaO	%	2.88	SMWW
MgO	%	0.106	SMWW
SO_3	%	0.003	SMWW
Cl-	%	0.011	SMWW
LOI	%	97.6	SMWW

SMWW: Standard Methods of Water and Wastwater (An Najah Univ. labs.)

The water samples have a pH of 7.98 (between 6-8) which complies with the findings of Neville (2015), who concluded that water having a pH in this range have no significant effect on compressive strength of concrete. According to BS 3148, the permissible limit of total dissolved solids (TDS) is 2000 ppm. All water samples tested have their TDS within the acceptable limits.

B. Properties of fresh cast stone mix and hardened cast stone

For each fresh cast stone mixture, slump test was conducted to investigate workability. The hardened samples were tested for compressive strength after 7, and 28 days, and absorption after 28 days. Figure 5. shows fresh mix and hardened samples of cast stone mix.

Figure 5. Fresh mix and hardened samples of cast stone mix

6. Results and Discussion

A. Slump test results:

Table 3. shows the variation of slump test results with w/c ratio of 0.7 and different replacement ratio. The workability decreased at replacement ratios of 20% and 100%, compared with workability of concrete with tap water.

Table 3. Comparison of slump test of fresh concrete

SW %	w/c	Slump(mm)	
0	0.7	95	
20%	0.7	48	
100%	0.7	20	

It is noticed that replacement of mixing fresh water with 20% and 100% of stone slurry wastewater reduces the slump more than 50% at w/c=0.7. From these results we may conclude that using stone slurry wastewater in general will reduce workability tremendously and more superplasticizer agent should be used to increase workability.

B. Compressive Strength Results:

Table 4. shows the variation of compressive strength of cast stone at different replacement ratios of tap water with stone slurry wastewater and for different ages.

Table 4. Comparison of maximum compressive strength at different replacement ratios of wastewater, for different ages

<table>
<tr><th rowspan="4">w/c</th><th rowspan="4">Age (days)</th><th colspan="3" rowspan="2">% Replacement of wastewater</th><th colspan="2">% Replacement of wastewater</th></tr>
<tr><th>20%</th><th>100%</th></tr>
<tr><th>0%</th><th>20%</th><th>100%</th><th colspan="2" rowspan="2">% reduction in max. stress</th></tr>
<tr><th colspan="3">Maxim. stress (MPa)</th></tr>
<tr><td rowspan="2">0.6</td><td>7</td><td>25.1</td><td>29.33</td><td>25.73</td><td>+16.85</td><td>+2.5</td></tr>
<tr><td>28</td><td>26.95</td><td>30.7</td><td>27.63</td><td>+13.9</td><td>+2.5</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="2">0.7</td><td>7</td><td>22.87</td><td>20</td><td>25.3</td><td>-12.5</td><td>+10.6</td></tr>
<tr><td>28</td><td>26.1</td><td>25.8</td><td>30.5</td><td>-1.15</td><td>+16.85</td></tr>
</table>

It is noticed that compressive strength increased at w/c ratio = 0.6 after 7 days and 28 days at replacement ratio (sw)=20% and (sw)=100%, and at w/c ratio = 0.7 after 7 days and 28 days with (sw)=100% but it was decrease after 7 days and 28 days with (sw)=20%.

It is clear from the results that the compressive strength has increased for most of the samples and decreased at a w/c ratio of 0.7 with (sw)=20%, however the compressive strength was not considerably changed by the replacement of tap water by stone cutting plants wastewater.

Figures 6. shows the variation of compressive strength of cast stone with different replacement ratios at w/c=0.6 , after 7 days and 28 days curing, Figure 7. shows the variation of compressive strength of cast stone with different replacement at w/c=0.7, after 7 days and 28 days curing.

Figures 8. shows the variation of compressive strength of cast stone with different replacement ratios after 7 days curing for different w/c ratios, and Figure 9. shows the variation of compressive strength of cast stone with different replacement after 28 days curing for different w/c ratios.

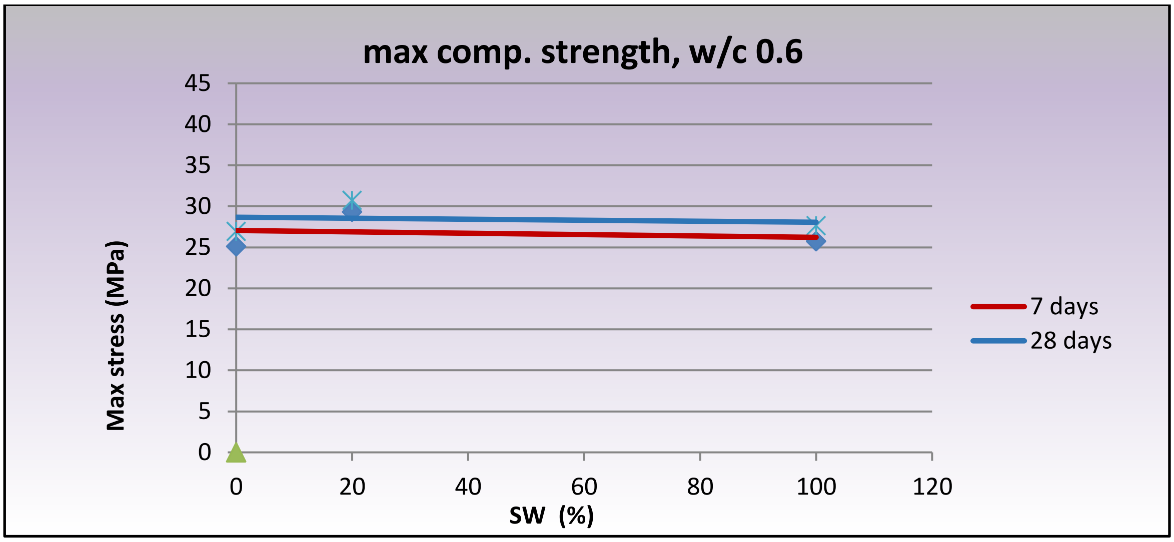

Figure 6. The variation of maximum compressive strength of cast stone with different replacement ratio , at w/c = 0.6

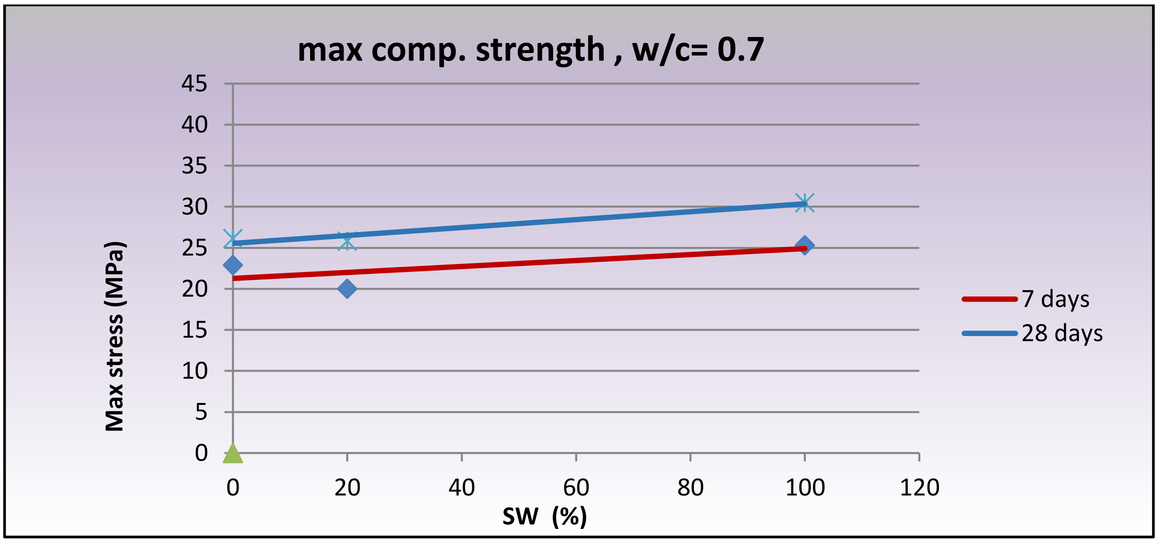

Figure 7. The variation of maximum compressive strength of cast stone with different replacement ratio , at w/c = 0.7

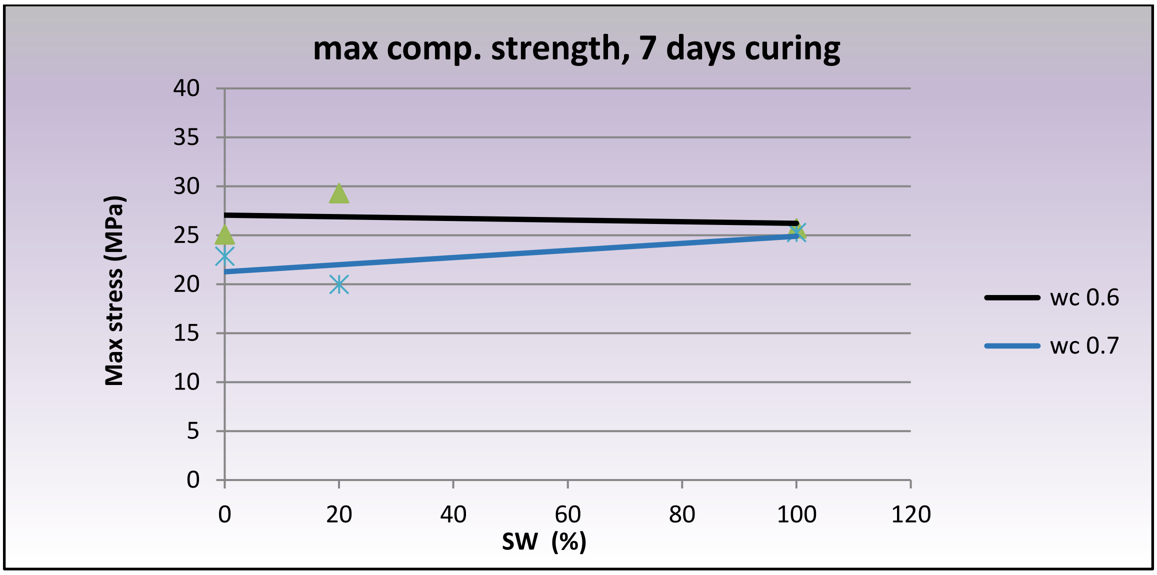

Figure 8. The variation of maximum compressive strength of cast stone with different replacement ratio , 7 days curing.

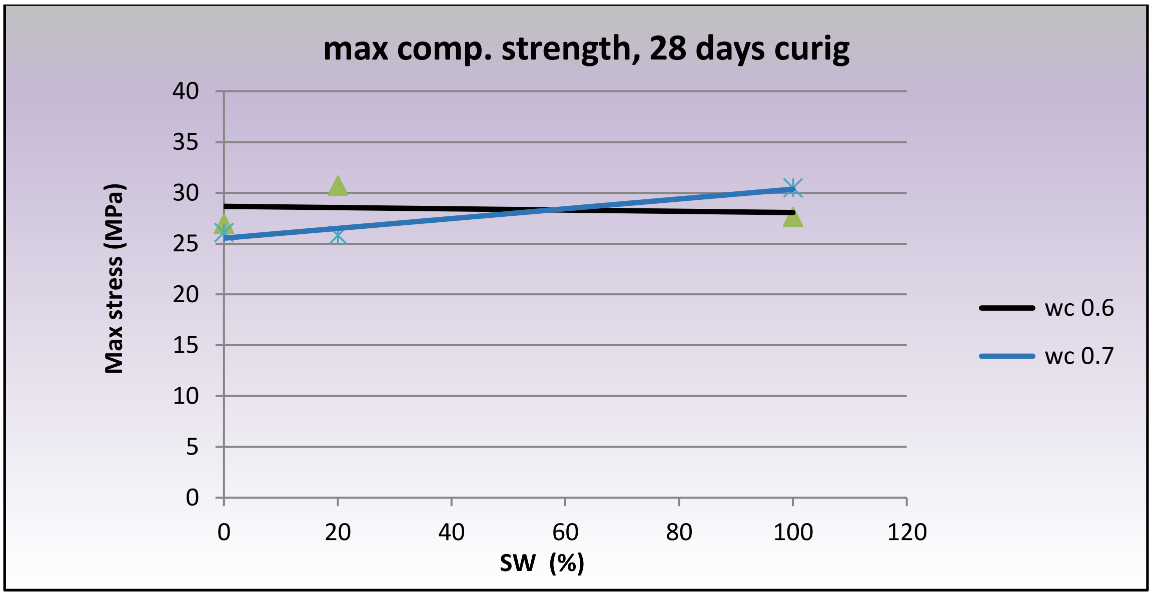

Figure 9. The variation of maximum compressive strength of cast stone with different replacement ratio , 28 days curing.

Therefore we may suggest using wastewater from stone slurry as replacement of mixing fresh water in production of low strength concrete or non-structural such as plane concrete.

C. Absorption Test results:

Table 5. shows the variation in natural absorption after 28 days curing of concrete samples made with the stone slurry wastewater compared with absorption of samples made with tap water at the same age. It is noticed that absorption increased upon replacement of tap water with stone slurry wastewater by 20%. The absorption is slightly higher than ASTM C194 specification for Class A of cast stones.

Table 5. Comparison of absorption at sw=20% replacement with tap water

water type / (sw %)	w/c	absorption after 28 days (%)	Specification (ASTM C 1195)
tap water (sw 0 %)	0.7	6.18	Class A: 6% max, Avg.: 5.6 max Class B: 4.6 max, Avg. : 4% max
Stone wastewater (sw20%)	0.7	6.61	

Note: results w/c=0.6 and at sw=100% is not available, the research is ongoing.

7. Conclusions and Recommendations

1- Result showed that using wastewater from stone slurry waste at w/c=0.6 in cast stone mixes increased the maximum compressive stress, at replacement ratio of 20% and 100% after all curing ages.

2- At w/c =0.7 the results showed minor reduction in maximum compressive stress after 7 days and replacement ratio of 20%, but increased by 10.6% at replacement ratio of 100%. However, the maximum compressive stress increased by 16.85% after 28 days curing, but no significant change in is observed after 7 days curing.

3- The result showed that replacement of tap water with stone slurry wastewater caused substantial slump reduction at w/c=0.6 and 0.7.

4- The water absorption is slightly higher than ASTM C1195 standard for Class A of cast stones.

5- The reduction of slump and the increase of water absorption, when using stone slurry wastewater, may be attributed to the fine suspended particles and chemical solvent available in the slurry stone wastewater.

6- From linear regression of the experimental results, it may be concluded that the optimum replacement ration of the stone slurry wastewater would be between 30% to 40%. This replacement ratio will produce cast stone with acceptable properties.

7- After 28 days curing the max compressive stress is almost the same at about 27 MPa, for both w/c of 0.6 and 0.7.

8- Using stone slurry wastewater at replacement ratio of 40%, will conserve similar amounts of fresh water for domestic use.

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