Study of the Effect of High Temperature on the Compressive and Tensile Strength of Cement Mortar Containing Round Waste Tire Rubber as a Sand Replacement in Mortar

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Abstract:

This paper investigated the effect of high elevated temperatures on the compressive and tensile strength of cement mortar fabricated by partially replacing sand (FA) by ground tire rubber (GTR) particles. The percentages by volume of GTR/FA were, 0% 5%, 10%, 15% and 20%. All mortar samples were prepared and cured in tap water for 28 days, then kept in laboratory atmosphere until the beginning of the test. The specimens were subjected to different target temperatures of 100, 200, 300, 400 and 500 °C. After reaching to the desired target temperature, the specimens were sustained at desired temperature for 2 hours. After heating, the specimens were allowed to cool at room temperature until the date of the test. The results showed that all mortar specimens exposed to high temperature suffered a significant decrease in both compressive and tensile strengths. The optimum GTR% which gave the highest relative compressive strength was in the range of 5% to 10% while that gave the highest relative tensile strength was in the range from 10% to 15%. The mass loss increased with increasing of temperature up to 500 oC and GTR%. In addition, at high temperature 500 ^{o}C it was noticed that no cracks appeared on the surface of specimens.

Introduction:

The management of worn tires poses a major problem for all third world countries. Also, with the increasing number of vehicles, the industrial development which several countries are currently knowing, and the small percentage of recycled worn tires (retreaded or used for other purposes) due to the absence of an adequate plan for eliminating this waste, these countries know surely a major environmental problem. The absence of statistics on this subject does not enable us today estimate suitably the mass of worn tires thrown in the nature or burned in public dumpsters. But if we compare these countries with the European Union Countries which took this problem in charge, through legislation, recycling companies, research, we can say that many countries are postponing the solution to this problem, and that the mass of worn tires can only be considerable. One of the recommended solutions to solve this environmental problem is to incorporate rubber aggregates resulting from cutting worn tires in the cement concretes [1-6].

Utilization of waste tires would eliminate castle pollution that is required to prevent degradation of air, land and water in the vicinity of the waste disposal sites. Also burning the remains of tire rubber for getting rid of them causes a very big pollution to the environment. Therefore, many studies [7-9] were directed to words avoiding the problems resulting from burning the remains of tire rubbers and studying the role of utilization of the ground waste tires rubber as aggregates in concrete. Many properties of the concrete can be improved using the tire chips in civil engineering applications such as low material density, high bulk permeability, high thermal insulation, high durability, and high bulk compressibility. On heating, a neat Portland Cement paste first expands owing to its normal thermal expansion. This expansion, however, is exposed to a contraction due to the shrinkage of the material as water is driven off from it. The contraction due to drying eventually becomes much larger than its normal thermal expansion and the material then begins to shrink. The temperature at which the maximum shrinkage is reached varies with the size of the specimen and the conditions of heating. It may be as high as 300^{o}C for air-dry specimens under conditions of fairly rapid heating. At more temperatures the neat Cement steadily shrinks, the contraction from the original dimensions amounting ultimately about 0.5 percent or more. During this process, severe cracking occurs [10]. Hydrated Portland cement contains a considerable proportion of free calcium hydroxide, which loses its water above 400-500^{o}C, leaving calcium oxide (quick lime). If calcium oxide (CaO) becomes wetted after cooling as exposed to moist air, it rehydrates to calcium hydroxide ($Ca(OH)_2$) accompanied by an expansion in volume that may disrupt a concrete, which has withstood a fire without disintegration [11].

Waste tires pose a health hazard since tire piles are excellent breeding grounds for mosquitoes. Because of the shape and impermeability of tires, they may hold water for long periods providing sites for mosquito larvae development. Waste tires also pose a serious fire hazard since waste tires and waste tire stockpiles are difficult to ignite. However, once ignited tires burn very hot and are very difficult to extinguish. A large tire fire can smolder for several weeks or even months, sometimes with dramatic effect on the surrounding environment. An end-of-life tire is a used tire that cannot or is not reused for its originally intended purpose and is not retreaded. Such tires may have a further use as a raw material for other processes or be destined for final disposal. End-of-life tires are called “scrap tires” in the United States [12]. However, all of the recycling re-uses and recovery practices combined only consume about 22% of the discarded tires. Thus, a need still exists for the development of additional uses for scrap tires [13-15]. Nowadays, waste tire disposal is a significant problem and finding an environment friendly and potentially attractive method is the greatest challenge. The difficulty in the recycling of the waste tire is that the tire rubber is a cross linked polymer that is hard to melt and to process [16-17].

The best fire resistant aggregate, which is characterized by a very fine crystalline texture or a non-crystalline basic material such as limestone, expands steadily until a temperature of about 900 ^{o}C is reached, then begins to contract owing to decomposition of calcium carbonate ($CaCO_3$) with liberation of dioxide carbon (CO_2). It has often been considered, on account of this decomposition, that the concrete with limestone has no fire resistance beyond this temperature [18]. Long series of tests on the fire resistance of structures have been carried out in Britain and USA. All concretes, which are considered the most fire resistant, attained a serious reduction in strength at a temperature above 600°C and fail if exposed for a considerable time to a temperature exceeding 900°C[19].

In the present investigation ground waste tires rubber was used as a partial replacement for fine aggregates by volume (0%, 5%, 10%, 15% and 20%). All mortars samples were exposed to five different temperatures 100, 200, 300, 400 and 500°C for 2 hours soaking time with heating rate of 10-20°C. The weight loss and residual compressive and tensile strengths due to exposure to those high temperatures were experimentally investigated in the present paper.

EXPERIMENTAION WORK:

The cement used in mortar mixes was ordinary Portland cement (CEM I). The properties of the used cement are given in Table 1. The used sand was siliceous sand with 100% passing ASTM sieve No. 4 with a fineness modulus of 2.75. The cement content was 400 kg/m3. The sand to cement ratio in the mortar mixes was remained equal to 3 to 1. The water/cement ratio (W/C) was 0.5 for all cement mortar mixes. The used ground waste tire rubber (GTR) in this research was produced by grinding the waste tires with special technique. The fine aggregates (FA) in all mixes were sand partially replaced by fine GTR particles. The percentages by volume of GTR/FA were 0, 5%, 10%, 15% and 20%. Sieve analysis of the used GTR and sand are given in Table 2. The physical properties of the used fine GTR are given in Table 3. Cubes (70 × 70 × 70) mm were prepared for testing under static compression. Cylinders of 75 mm diameter and 150 mm height were prepared for testing under indirect tension test. The mortar constituent materials were batched separately by weight. Mixing was performed in a small rotating-drum mixer. First, cement and waste tire rubber were dry mixed until a homogeneous mix was observed before mixing the sand to it, and then water was gradually added while mixing continued for about five minutes. All specimens were cast in steel molds, then demolded after 24 hours and cured in fresh water for 28 days. All specimens were cast and treated under the same environmental conditions. After curing, the specimens were exposed to temperatures of 100, 200, 300, 400 and 500°C and kept at that temperature for 2 hours in semi-open muffle furnace with an average heating rate of 10 ^{o}C per minute. After heating, the specimens were left to cool in air until the time of testing. The compressive and indirect tensile tests were carried out in a hydraulic universal testing machine of 100 ton capacity.

Table 1 :Properties of the used cement

Property	Results	E.S.S. No. 371/1991
Initial setting time	1.45 hr	≥ 45 min
Final setting time	4.25 hr	≤ 10 hr
Fineness, μm	8	≤ 10
Compressive strength (kg/cm^2) After 3 days After 7 days After 28 days	 225 297 379	 ≥ 180 ≥ 270 ≥ 360

Table 2 :Sieve analysis of GTR and sand.

Sieve Opening, mm	% passing		E.S.S. No. 1109/71
	GTR	Sand	
5	100	100	90-100
2.5	100	97.8	75-100
1.25	13.4	84.9	55-100
0.62	3.8	58.4	35-59
0.31	1.6	8	8-30
0.16	0.6	2.2	0-10

Table 3 Physical properties of GTR.

Property	GTR	Sand
Specific gravity	0.9	2.45
Unit weight g/cm³	0.67	1.7
Absorption %	1.9	0.42
Fineness Modulus	3.81	2.45

TEST RESULTS AND DISCUSSION

1- Compressive Strength

The effect of high temperatures on the relative compressive strength of mortar specimens produced by partial replacement of sand by (GTR/FA, % = 0, 5, 10, 15 and 20%) is shown in Fig. 1. The relative compressive strength showed in the figure is ratio multiplied by 100 of the strength of specimen exposed to high temperature to that of the unheated specimen at the same GTR/FA%. It is clear that all mortar mixes exposed to fire suffered a significant decrease in compressive strength. The average relative compressive strength for all GTR/FA% was about 93, 90, 83, 75 and 56 % for target temperatures of respectively 100, 200, 300, 400 and 500 ^oC. The small gradual decrease in the compressive strength at low temperature may be due to the existence of rubber particles absorbs the volume change occurred in the specimens due to heating. At high temperature (500 ^oC), higher reduction in compressive strength is observed and this may be due to melting of the rubber particles and increasing porosity in the mortar specimens. Thermal decomposition of some binding products such as Ca-sulphate- aluminate hydrate and calcium silicate hydrates may also reasons for the higher reduction in the compressive strength at high temperatures..

Figure 2 demonstrates the effect of GTR/FA % on the relative compressive strength of mortar specimens at different high temperatures. The figure clearly indicate that the optimum GTR % for high temperatures applications under compression loads is ranged from 5% to 10 %.

To explain the effect of GTR/FA% on the compressive strength of mortar, the strength of specimen exposed to high temperature and containing GTR was divided by that of 100% sand and exposed to the same target temperature. This is defined as the compressive strength ratio. The effect of GTR/FA% on the strength ratio at different exposure temperature including room temperature is shown in Fig. 3. The same trend for all target temperature is observed, i.e linear reduction in the strength ratio with increasing GTR/FA%.

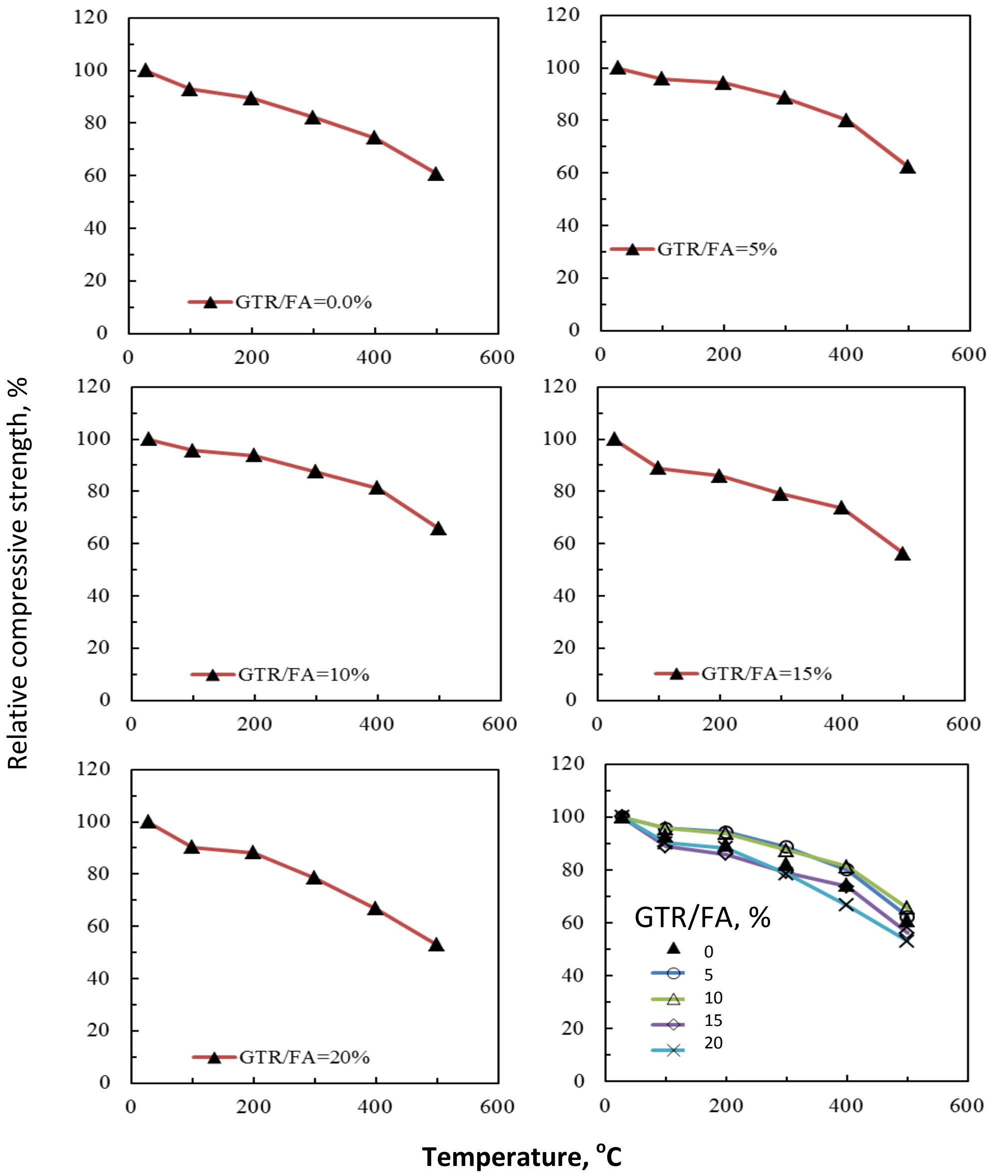

Fig. 1 Relative compressive strength against temperatures for different GTR/FA %.

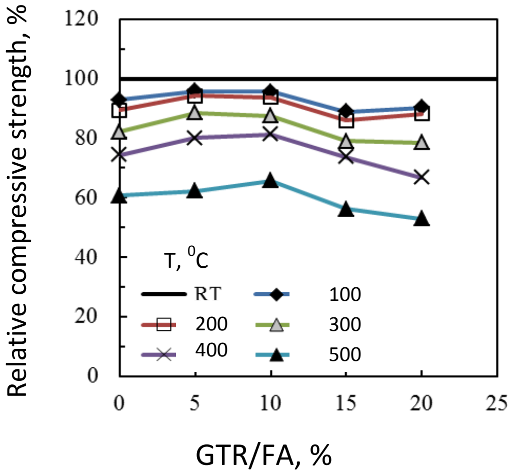

Fig.2 : Effect of GTR % on the relative compressive strength

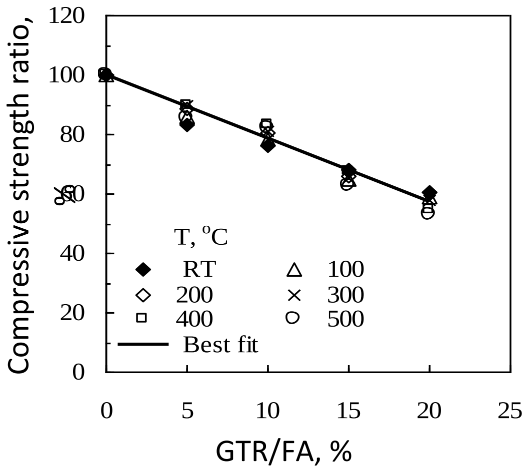

Fig.3: Effect of GTR % on the compressive strength ratio

2- Tensile Strength

The tensile strength of GTR mortar specimens shows similar trends as that of compression. The effect of high temperatures on the relative tensile strength of mortar specimens fabricated by partial replacement of sand by (GTR/FA % = 0, 5, 10, 15 and 20%) is shown in Fig. 4. The relative tensile strength showed in the figure is ratio multiplied by 100 of the strength of specimen exposed to high temperature to that of the unheated specimen at the same GTR/FA%. It is clear that, all mortar mixes exposed to fire suffered a gradual decrease in the relative tensile strength with increasing high temperatures.

The average relative strength for all GTR/FA% was about 97, 94, 86.5, 81.5 and 64 % for target temperatures of respectively 100, 200, 300, 400 and 500 ^{o}C. These average relative strengths are higher to some extent to those recorded under compression. This means that the degradation in the strength in the case of tensile stresses is smaller than that in the case of compressive stresses. This is expected, because the small resistance of rubber particles to compression load compared to its better resistance to tensile loads. The small gradual decrease in the tensile strength at low temperature may be due to the existence of rubber particles absorbs the volume change occurred in the specimens due to heating. At high temperature (500 ^oC), higher reduction in the tensile strength is observed and this may be due to melting of the rubber particles and increasing porosity in the mortar specimens. Thermal decomposition of some binding products such as Ca-sulphate-aluminate hydrate and calcium silicate hydrates may also reasons for the higher reduction in the tensile strength at high temperatures. Visual examination of specimen surfaces of GTR mortar after exposure to high temperatures up to (500 ^oC) reveals no cracks appeared on such surface. This indicates that the presence of GTR absorbed any volume changes in the matrix as a result of thermal expansion.

Figure 5 demonstrates the effect of GTR % on the relative tensile strength of mortar specimens at different high temperatures. The figure clearly indicates that the relative tensile strength increases with increasing GTR up to 10% in some cases and up to 15% in other cases and after that it decreases at all temperatures. Thus we can conclude that the optimum GTR % for high temperatures applications under tensile loads is ranged between 10% and 15%.

To explain the effect of GTR/FA% on the tensile strength of mortar, the strength of specimen exposed to high temperature and containing GTR was divided by that of 100% sand and exposed to the same target temperature. This is defined as the tensile strength ratio. The effect of GTR/FA% on the tensile strength ratio at different exposure temperature including room temperature is shown in Fig. 6. The same trend for all target temperature is observed.

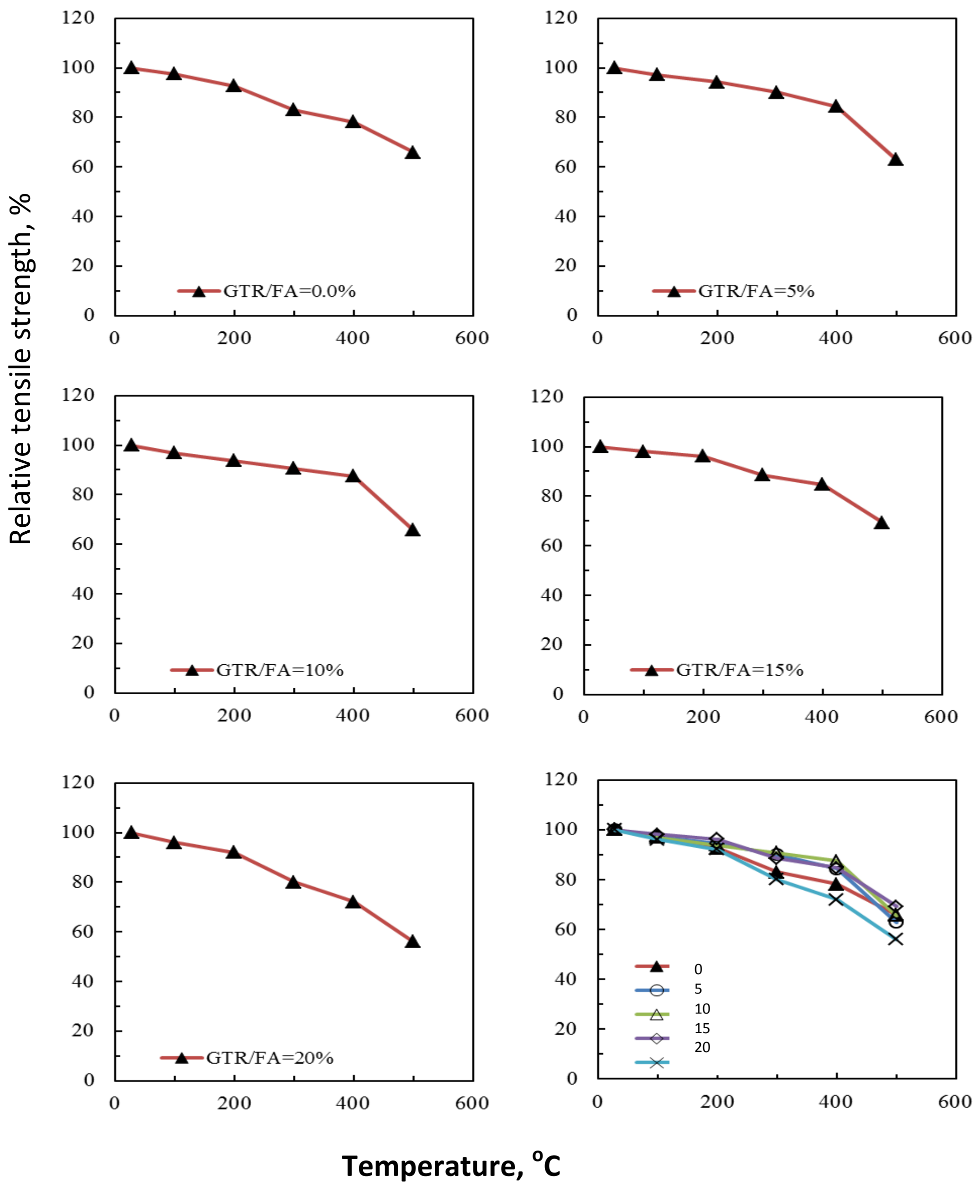

Fig. 4 :Relative tensile strength against temperatures for different GTR/FA %.

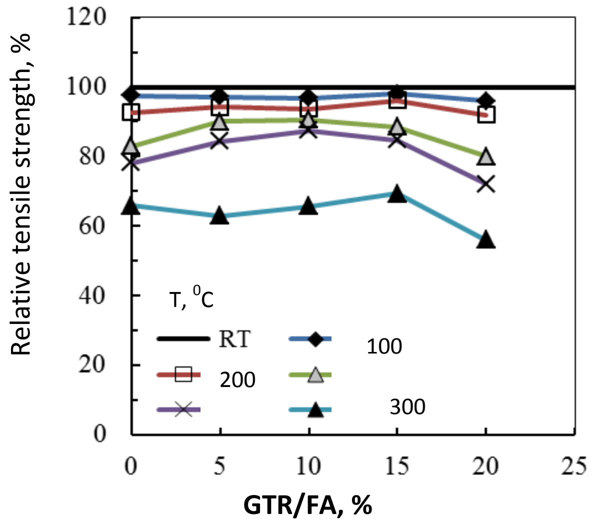

Fig.5 :Effect of GTR % on the relative tensile strength

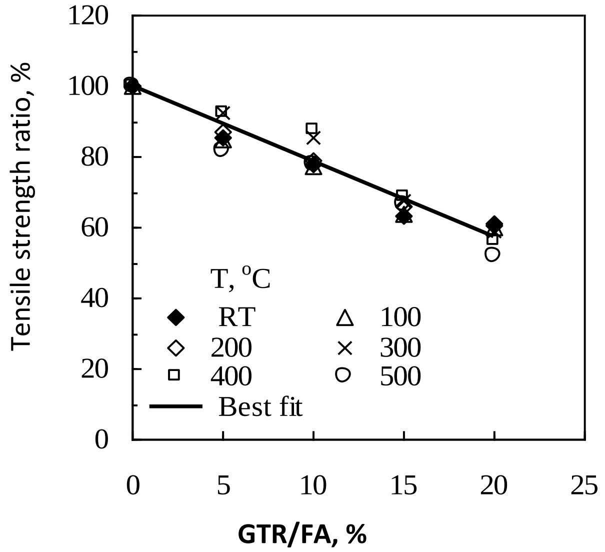

Fig.6 :Effect of GTR % on the tensile strength ratio

3- Mass loss

Heat induced mass losses due to water evaporation and melt of rubber for all mixtures are shown in Figs. 7, the mass loss illustrated in this figure represents the normalization of the difference in mass loss between the unheated and heated specimens to that of the unheated specimens multiplied by 100. All mixtures demonstrated an increase in the mass loss percentage with increasing temperature. These losses are increased with increasing GTR to high temperature.

The loss rate is low at the first stages of heating up to temperature of 200^{o}C. When the heating temperature is under 200^{o}C, the mass loss is completely caused by quick evaporation of capillary water, and concrete undergoes a physical process. For a temperature between 200 and 400^{o}C, the weight loss is mainly caused by gradual evaporation of gel water and melt of rubber, and the concrete undergoes a mix physico-chemical process. For a temperature over 400°C, the weight loss is mainly caused by the melt of rubber and evaporation of chemically combined water (dehydration) and decomposition, so the concrete undergoes a chemical process [10].

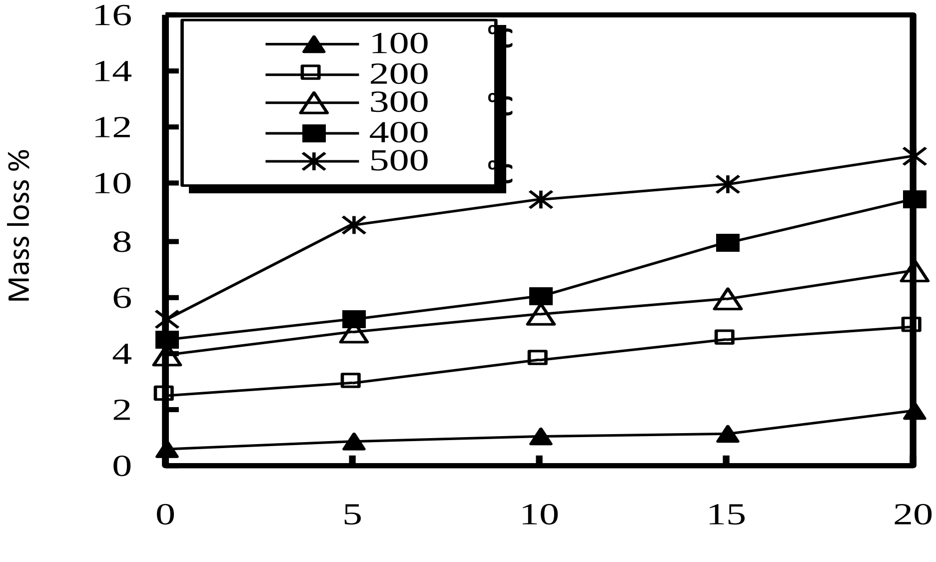

Fig.7: Effect of GTR % on mass loss percentage.

CONCLUSIONS

This paper investigated the effect of high elevated temperatures on the compressive and tensile strength of cement mortar fabricated by partially replacing sand by ground waste tire rubber particles. The results of the work reached to the following conclusions:

1- All mortars specimens exposed to high temperatures showed a decrease in both compressive and tensile strengths with increasing temperature. The reduction in the compressive strength was higher than that recorded in tensile strength.

2- The GTR/FA% showed remarkable effect on the mortars compressive and tensile strengths after their exposure to high temperature, the compressive strength and tensile strengths of rubberized mortars decreased with increasing of GTR/FA%.

3- The optimum GTR% which gave the highest relaive compressive strength was in the range from 5% to 10% while that gave the highest relative tensile strength was in the range from 10% to 15%.

5. The mass loss increased with increasing of temperature up to 500^{o}C and GTR%.

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