Concrete strength under different modes of thermo-mechanical loading conditions

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This paper presents the results of an experimental program on the effect of four test methods, representing four thermo-mechanical loading combinations of temperature conditions, on the relative compressive strength of concrete. These test methods include the Residual UnStressed Test (RUST) (heating followed by cooling outside the furnace before fracturing), the Residual Stressed Test (RST) (loading during heating time followed by cooling outside the furnace before fracturing), the Unstressed Test (UST) (fracturing inside the furnace just after heating) and Stressed Test (ST) (loaded during heating followed by fracturing the specimen after reaching the desired exposure time). These test methods were applied on five concrete mixes. The first three mixes represented normal strength concrete made with gravel, dolomite and basalt as coarse aggregates. The other two mixes represented respectively high strength concrete made with basalt as coarse and fine aggregate and light weight concrete made with leca as coarse aggregate. These mixes were subjected to two target temperatures of 200°C and 550°C for 1.5 hours. In the ST and RST, the specimens were subjected to load ratios equal to 40%, 60% or 80 % from the corresponding maximum load of the unheated specimens. Test results indicated that the high temperature tests must be performed following the sequence of the ST test method. Also, it was found that, for concrete subjected to high temperature during their service life, load ratio of 60% can be a safe load at low temperatures up to 200°C. Above 200°C, the design load must not exceed 40 % of that of the unheated specimens.

يتناول هذا البحث بالدراسة المعملية تأثير طرق الإختبار الميكانيكية الحرارية على مقاومة الخرسانة للضغط عند تعرضها لدرجات الحرارة العالية (٢٠٠ م°، ٥٥٠ م°) لمدة ٩٠ دقيقة بعد وصول درجة حرارة سطح العينة لهذه الدرجة. وقد تمت دراسة أربعة انماط مختلفة من طرق الاختبار الميكانيكية الحرارية والتى تمثل حالات تحميل واقعية. ففى الاختيار الأول تم تعريض العينات لدرجات الحرارة المطلوبة ثم تبرد هذه العينات فى الهواء لمدة ٢٤ ساعة قبل الكسر(RUST). أما الاختبار الثاني (UST) فقد تم تسخين العينة لدرجة حرارة الإختبار ثم تترك لمدة ١,٥ ساعة تبدأ من ثبوت درجة حرارة الإختبار ثم تحمل العينة حتى الكسر داخل الفرن. وفى الإختبار الثالث (RST) يتم تحميل العينات بنسبة تحميل تساوى ٦٠% أو ٤٠% من حمل الكسر للعينات التى لم تعرض لأية درجة حرارة عند نفس الدرجتين ويتم ترك العينه تحت تأثير الحرارة لمدة ١,٥ ساعة ثم يتم إخراج العينه لتبرد خارج الفرن حيث يتم إجراء إختبار الكسر لها بعد ٢٤ ساعة. وفى الاختبار الرابع (ST) فقد تم تسخين عينات الاختبار وهى واقعه تحت تأثير حمل ميكانيكي بنسبة ٨٠% أو ٦٠% أو ٤٠ % من حمل الكسر للعينات التى لم تعرض لأية درجة حرارة وذلك فى الإختبار الأول. وفى الإختبار الرابع يتم رفع الحمل حتى الكسر دون خروج العينة لخارج الفرن (ST). وقد تم تطبيق هذه الطرق على ثلاثة أنواع من الخرسانة (خرسانة عادية، خرسانة خفيفة وخرسانة عالية المقاومة) تمثل خمس خلطات خرسانية بأنواع مختلفه من الركام الخشن. ومن أهم النتائج التى توصل اليها البحث أن أعلى فقد فى المقاومة كان للعينات الغير محملة والمختبرة داخل الفرن عند تعرضها لدرجة حرارة ٢٠٠ م°. ولكن عند درجة حرارة ٥٥٠م° كانت أقل النتائج للعينات الغير محملة والتى بردت خارج الفرن. وقد أوضحت النتائج أنه حتى ٢٠٠ م° فإن حمل التصميم يجب ألا يزيد عن نسبة ٦٠% من حمل الكسر للخرسانه فى درجة حرارة الغرفة وألا تزيد هذه النسبة عن ٤٠% فى حال زيادة درجة الحرارة بعد ٢٠٠ م°.

Keywords: Normal strength concrete, High strength concrete, Light weight concrete, Test methods, Compressive strength

1. Introduction

Concrete has continuous widespread uses in the places exposed to high temperatures such as thermonuclear stations and concrete oven lining. Fire is also one of the natural hazards which attack structural elements. The damage in buildings continuously exposed to fire is largely caused due to high temperature. When concrete is exposed to heat, many forces such as physical enforcement as cement hydration, chemical decomposition, differential thermal expansion stresses and external loads are occur. Some of these forces have an affirmative action on the strength of concrete and the others have an opposite effect. The increase in temperatures above 100^{O}C may supply activation energy to improve cement hydration as a physical action which can be limited by differential thermal stresses [1, 2].

Depending on the heating rate and boundary conditions, exposure to high temperatures can lead to explosive spalling of concrete. High temperatures also cause chemical and micro-structural changes, such as migration of water (diffusion and drying), increased dehydration, internal thermal incompatibility and changes in chemical compositions of hardened cement paste and aggregate. In general all these changes cause the strength of concrete to decrease and the deformation to increase [1-5]. Moreover, based on the limited amount of experimental data available, it has been found that [6-8] this strength loss varied with a number of factors, including the combinations of loading and heating regimes (stressed test, unstressed test, and unstressed residual property test), the heating rates, original compressive strength, porosity or permeability which can vary with the use of silica fume, the type of aggregate (normal weight calcareous and siliceous, or light weight), and moisture content.

Many researches had been carried out to study the behavior of High Strength Concrete (HSC) in comparison with that of Normal Strength Concrete (NSC) at high temperature [6-11]. Most of them agreed that the behavior of HSC differs from that of normal strength concrete NSC under the same heating conditions. A review on high temperature performance of HSC [6] identified two main differences between HSC and NSC: 1 the difference in heat-induced relative strength loss in the intermediate temperature range (100^{o}C to 400^{o}C) and 2 the occurrence of explosive spalling failure in HSC specimens at similar temperature. On the other hand, Chan et al. [10] showed that HSC losses its mechanical strength in a manner similar to that of NSC. Investigations on the structural Light Weight Concrete (LWC) in the USA showed that it has better resistance to high temperature compared to NSC [12]. The opposite experience was found in Norway [13]. This contradiction was due to the different fire loads.

The experimental data related to the behavior of concrete at high temperature under combination of loading and heating regimes are rare [7, 14, 15]. Most of these researches studied such behavior under three test methods; stressed test, unstressed test, and residual unstressed test. The results of these works indicated that, for stressed and unstressed tests, the compressive strength of HSC varies in a different and more unfavorable manner with temperature than that of NSC. The differences are more pronounced in the temperature range between 25^{o}C and 400^{o}C, where HSC sustained markedly higher strength loss than NSC [15]. Differences become less significant at temperature above 400^{o}C.

Concrete under its service conditions in the places such as thermonuclear stations, oven lining or guided missiles is subjected to different patterns of thermo-mechanical loadings. Also, with the continuous widespread of concrete in construction, crushed stones aggregates (dolomite and basalt) took place in the Egyptian local market as an alternative to gravel. The chemical and mineralogical composition of these aggregates play a vital role in the behavior of concrete at elevated temperature Thus, this research program aims to study the effect of elevated temperature on the compressive strength of concrete having different strengths and different types of coarse aggregates and subjected to the three common modes of thermo-mechanical loadings conditions (residual unstressed test, unstressed test and stressed test) besides another test method suggested by the authors which is the residual stressed test.

2. Materials and method

All materials used in the fabrication of test specimens were locally available materials. Three types of natural aggregates, i.e. gravel, dolomite and basalt, and one type of artificial light weight aggregate, i.e. leca, were used as coarse aggregates. All coarse aggregates were of maximum nominal size of 20 mm. The four types of coarse aggregates were sieved and separated to three different sizes. According with ASTM C33-97[16] for natural weight aggregate and ASTM C330-89 [17] for light weight aggregate, a percentage from each size were taken to get the same grading and fineness modulus. Ordinary siliceous sand and crushed fine basalt were used as fine aggregates. The properties of the used coarse and fine aggregates are given in table 1. Type I ordinary Portland cement was used in the fabrication of all mixes. Egyptian silica fume containing 97% SiO_2 according to ASTM C1240-97 was used as mineral admixture for the production of HSC. Super-plasticizer (Sikament-163-M according with ASTM C494-92 Type F from SIKA Company) was used as chemical admixture to overcome the loss of workability as a result of silica fume addition. The dosage of the used super-plasticizer was 2.16% of cement weight.

The above materials were proportioned using the ACI mix design method to give five concrete mixes. The first three mixes represented NSC (Mix I, Mix II, and Mix III) made respectively with gravel, dolomite and basalt as coarse aggregates and sand as fine aggregates. Mix IV simulated LWC in which leca was used as coarse aggregate and sand as fine aggregates. The last mix, Mix V, simulated HSC made with basalt as coarse and fine aggregates. Materials required to produce one cubic meter of concrete from the five mixes are given in table 2. All mixtures were cast in a cylindrical moulds, 200 mm height and 100 mm diameter according to ASTM C192/C192M-92, C39-M and C67-M. The specimens were stored for 24 hrs before curing by immersing in water according to ASTM 511-96 for 28 days at 23-30°C.

The experimental program suggested for the present work includes the exposure of concrete specimens fabricated from the previously mentioned five concrete mixes to four test methods, representing four thermo-mechanical loading conditions as illustrated in table 3. These include Residual Un-stressed Test (RUST), Un-stressed Test (UST), Residual Stressed Test (RST) and Stressed Test (ST). A schematic representation for the four test methods is shown in fig. 1. In the RUST method, the specimens were heated in the furnace without loading to the desired Target Temperature (TT). The ambient temperature is held constant for 1.5 hrs. The specimen is then allowed to cool at room temperature by natural cooling before loading to failure after 24 hrs, fig. 1-a. In the UST test method, fig. 1-b, the specimen was heated without any mechanical loading to a pre-selected TT. The temperature was held at this target level for the desired exposure time (1.5 hours). After that, specimen was loaded to failure inside the furnace. In the RST method, the specimens were subjected to a pre-selected load ratio (L-ratio) from the fracture load of the corresponding fracture load of the un-heated specimen and kept under this L-ratio for 1.5 hr at certain pre-selected target temperature. After that, the load is released and specimen is allowed to cool at room temperature before being reloaded after 24 hours as schematically shown in fig. 1-c. In the ST method, the specimen was subjected to a pre-selected L-ratio. The specimen was heated under this loading condition until it reached a pre-selected specified TT. The specimen was kept under this temperature for the specified exposure time, 1.5 hr, before increasing the load to fracture while the test specimen was inside the furnace, fig. 1-d.

The selected target temperatures were 200°C and 550°C. In all cases, the specimens were sustained in the electric furnace after reaching the desired TT for 1.5 hrs. Three specimens were cast and tested from each case. The measured compressive strengths of the reference specimens were respectively 29.9, 31, and 31.9 MPa for NSC made respectively with gravel (Mix I), dolomite (Mix II), and basalt (Mix III) as coarse aggregates, 17 MPa for LWC (Mix IV) and 55.5 MPa for HSC (Mix V). An electric furnace of 700°C maximum temperature was designed for this purpose. The furnace was connected to a temperature control unit. A thermocouple was placed in the middle of the furnace to monitor the temperature near the specimen surface. The average heating rate in the furnace was 8°C/min. All tests were conducted under a load control Universal Testing Machine of 1000 kN maximum capacity.

Table 1

Properties of the used coarse and fine aggregates

Physical properties	Coarse aggregates				Fine agg.	
	Gravel	Dolomite	Basalt	Leca	Sand	Basalt
Bulk density, t/m^3	1.75	1.48	1.64	0.515	1.79	1.70
Specific gravity	2.57	2.45	2.76	0.724	2.70	2.56
Fineness modulus	7.63	7.63	7.63	7.62	2.55	2.79
Absorption, %	0.9	1.4	1.05	21	-	-
Impact value, %	12	17.5	14.8	71	-	-
Organic materials	Nil	Nil	Nil	Nil	Nil	Nil
Clay, %	Nil	Nil	Nil	3.1	1.5	2.5
Thermal expansion (10^{-6}/°C)	12.5	7.8	7.4	6.1	-	-
Thermal conductivity (W.m^{-1} k^{-1})	4.3	2.0	1.4	0.11	-	-

Table 2
Compositions of mixes by weight in kg/m^3

Materials	Mixes				
	NSC			LWC	HSC
	I	II	III	IV	V
Cement	350	350	350	400	405
Gravel	1120	-	-	-	-
Dolomite		947	-	-	-
Basalt	-	-	1049	-	1049
Leca	-	-	-	250	-
Sand	627	779	779	469	
Fine basalt	-	-	-	-	695
Water	200	200	200	250	180
Silica fume	-	-	-	-	45
Super-plasticizer	-	-	-	-	9.72

Table 3
Experimental program of the present work

Test Conditions			Mix I	Mix II	Mix III	Mix IV	Mix V
Test Method	T °C	L-ratio					
RUST	200	-	√	√	√	√	√
	550	-	√	√	√	√	√
UST	200	-	√	√	√	√	√
	550	-	√	√	√	√	√
RST	200	60%	√	√	√	√	√
		40%	√	√	√	√	√
	550	60%	√	√	√	√	√
		40%	√	√	√	√	√
ST	200	80%	√	√	√	√	√
		60%	√	√	√	√	√
		40%	√	√	√	√	√
	550	80%	√	√	√	√	√
		60%	√	√	√	√	√
		40%	√	√	√	√	√

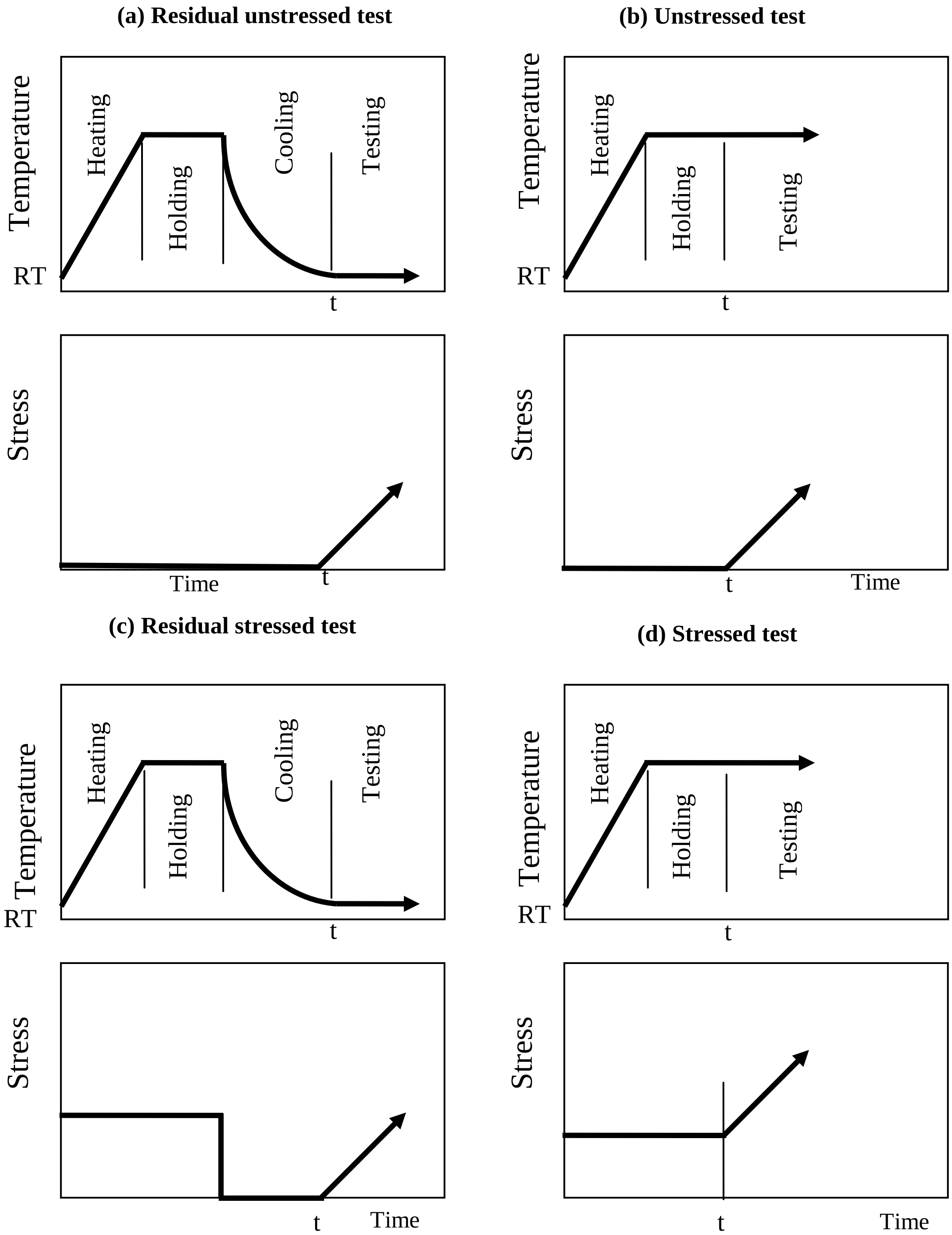

Fig. 1. Schematic temperature and load histories for the four thermo-mechanical tests.

3. Results and discussions

3.1. Un-Stressed Test (UST)

The results of the UST when the target temperatures are respectively 200°C and 550ºC are shown in figs. 2 and 3. The results of the RUST at the same heating conditions appear in the figures. At TT of 200°C, the relative compressive strengths for all concrete mixes under the UST conditions are less than those under the RUST conditions and the lowest value is recorded for Mix IV (LWC mix) with marginal difference between the remaining four mixes. Temperature of 200°C may supply un-hydrated cement particles with a additional activation energy to enforce its hydration. This could be beneficial to concrete strength development in a physico-mechanical process. Pore pressure influences the rate of hydrothermal reactions and generates tensile stresses in concrete. Also, thermal expansion may limit the gain in strength at this temperature [1, 18].

The results at TT of 550°C are opposite to those at 200ºC, where the relative compressive strength results under the UST test method are greater than those under the RUST test method. This is because at high temperature and under RUST conditions, chemical decomposition of cement components and releasing of free lime which combines again with the moisture or CO_2 from surrounding atmosphere during cooling outside furnace, cause dehydration. This is accompanied by large volume changes which may disrupt the concrete. This chemical action represents the main factor which causes the sharp loss in the compressive strength [2-4]. The absence of moisture and CO_2 eliminate this effect when the concrete specimens are fractured inside the furnace while still hot under the UST conditions.

The comparison between the results of the different concrete mixes when the TTs are 200ºC and 550°C under UST conditions as shown in fig. 4 reveals that two main factors affect the test results, i) differential thermal expansion and ii) the effect of heating on the crystallinity of aggregate. Using basalt as fine and coarse aggregate (Mix V) minimizes the effect of differential thermal expansion and results in good crystallinity at high temperature which improves the strength at 550 °C than that at 200 °C. In Mix IV, sintering of leca particles at 550ºC decreases the effect of the high differential thermal expansion between leca as coarse aggregate and sand as fine aggregate and thus improves the relative strength of Mix IV at 550ºC than that at 200 °C. Using both fine and coarse aggregate with different thermal expansion such as in the case of Mix III results in little improvement in strength at 550ºC. The decomposition of dolomite, at 550ºC in the case of mix II results in a smaller relative compressive strength at high temperature. In the case of Mix I, the main factor in retarding the strength development at 550ºC is the start of gravel transformation from low α quartz to high β quartz. This test method highlights the importance of the effect of cooling methods, differential thermal expansion between fine and coarse aggregates and the behavior of coarse aggregate when exposed to high temperature.

3.2. Residual Stressed Test (RST)

Fig. 5 shows the results of the RST at L-ratios of 40% and 60% and TT of 200ºC in comparison with those of the RUST at the same heating conditions. The results indicate that the relative compressive strengths under the RST are slightly less than those under RUST for both L-ratios and for all mixes. The figure also demonstrates that, under RST condition, with increasing the L-ratio the relative compressive strength decreases for all mixes. This may be due to the partial damage due to mechanical loading during heating. This damage increases with increasing L-ratio and thus resulting in a decrease in the final measured strength. This damage does not occurred under the condition of RUST and so higher residual strength is recorded with this test condition compared to that of the RST.

The results of the RST test method at 550ºC and L-ratio of 40% is shown in fig. 6. The results of the RUST under the same heating conditions are also presented in the figure. The specimens subjected to L-ratio of 60% failed before reaching the desired exposure time of 1.5 hours or before reaching the desired TT of 550°C and thus their results will be discussed under the sequence of ST in the next section. The figure illustrates that at this high temperature, the relative compressive strengths measured under RST are larger than those under RUST for all mixes. This indicates the contribution of the cracks that developed as a result of the pre-loading to 40% in accommodation of the volume expansion as a result of cooling after heating and thus reduces the internal stresses due to volume expansion.

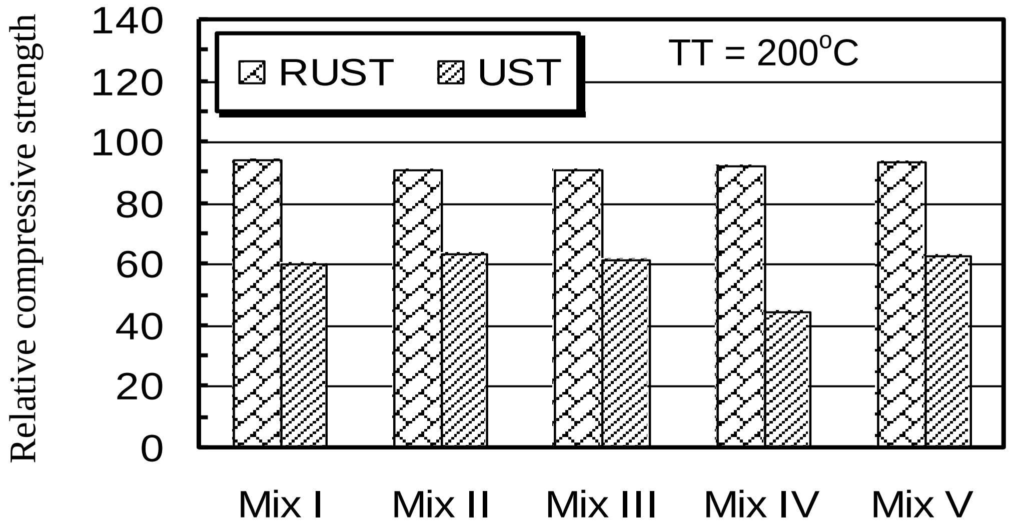

Fig. 2. Relative compressive strengths for different mixes under UST and RUST test methods at TT = 200°C.

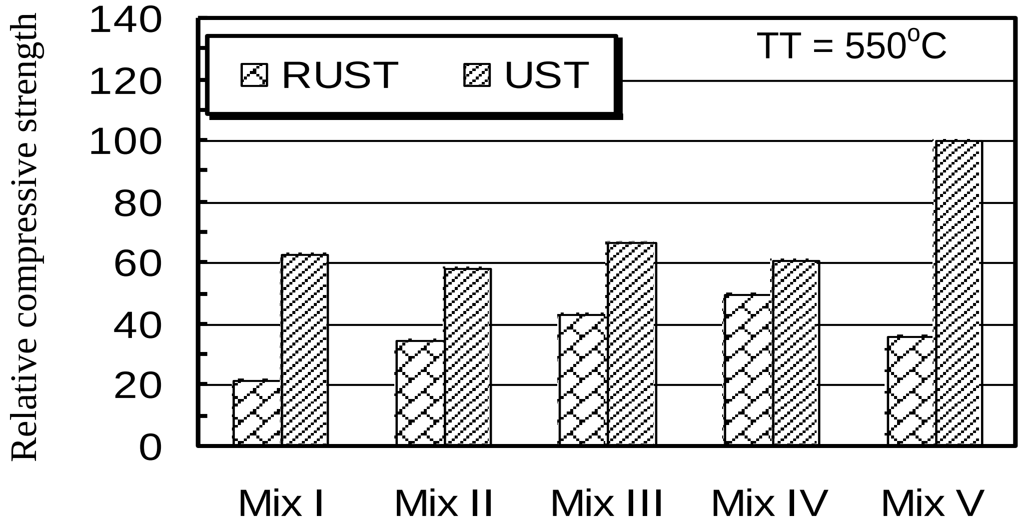

Fig. 3. Relative compressive strengths for different mixes under UST and RUST test methods at TT = 550°C.

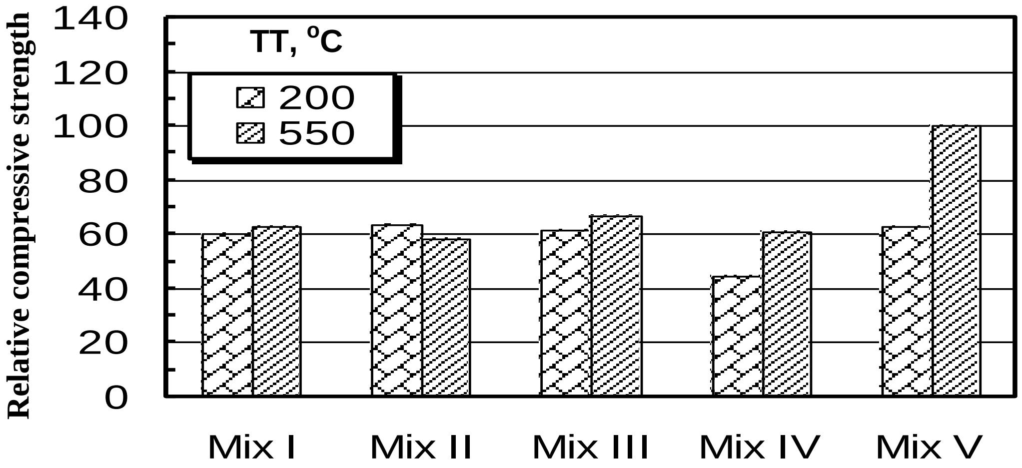

Fig. 4. Effect of target temperature on the relative strengths of different mixes under UST conditions.

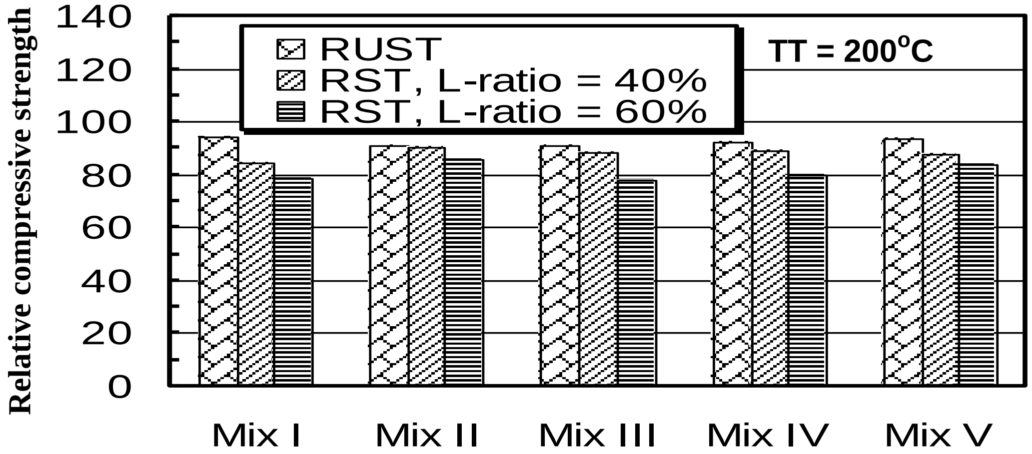

Fig. 5. Relative compressive strength for various mixes under RUST and RST conditions at TT = 200°C.

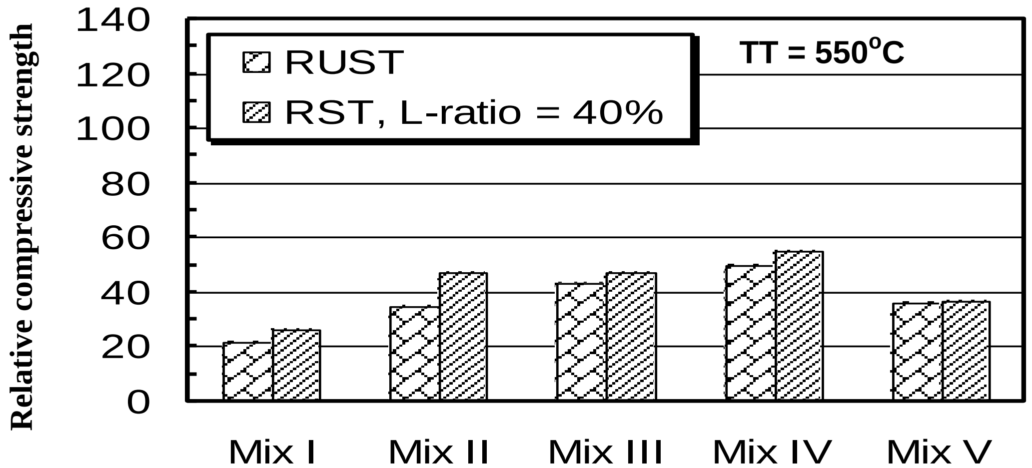

Fig. 6. Relative compressive strength for various mixes under RUST and RST conditions at TT = 550°C.

3.3. Stressed Test (ST)

When loading the specimens of the different concrete mixes under the sequences of ST by L-ratio equals to 80% at TT of 200°C, all specimens failed under this load ratio before reaching the desired exposure time of 1.5 hr. The life time of the different mixes at these conditions for mix I, Mix II, Mix III, Mix IV and Mix V are respectively 15, 24, 15, 16 and 30 minutes. On loading at L-ratio of 80% with the desired TT of 550°C, all specimens from the different mixes failed before reaching this TT. The recorded temperatures at failure were 250, 280, 300, 270 and 320°C for respectively mixes from I to V. The small life time for Mix IV and high life time for Mix V can be attributed to the fact that, the degree of damage under load depends on the strength of concrete where damage in HSC starts at about 90% of the ultimate load at room temperature.

Results of the relative compressive strengths for the five concrete mixes under ST conditions and L-ratios of 40% and 60% at TT equals to 200 °C are illustrated in fig. 7. The results of the RUST under the same heating conditions are also represented in the figure. Results in the figure show that loading by 60% during heating results in a higher relative compressive strengths for the five mixtures considered and the effect is more pronounced in the case of Mix I (gravel concrete mix). This may be attributed to the formation of new cracks and opening of existing cracks or voids in the matrix under the effect of the applied load. These cracks absorb the expansion due to thermal stresses which is higher in the case of Mix I. At this TT, the release of thermal loads due to cooling may be reasonable for the increase in the relative compressive strengths under RUST compared to those under ST conditions.

When loading by L-ratio equals to 60% at TT of 550°C, Mix V and Mix IV did not fail before approaching the desired TT and stayed at this target temperature for 5 min and 60 min respectively. On the other hand, all the normal strength concrete mixes (Mix I, Mix II and Mix III) failed before approaching the desired TT. Mix III failed at 390°C, Mix II failed at 350°C and Mix I failed at 310°C. Fig 8 illustrates the results of the five concrete mixtures under ST conditions when the L-ratio is 40% and the TT is 550°C.

A wide range with a variant attitude was occurred between the results of this test and those from the RUST exposed to target temperature of 550°C for 1.5hrs, where all the results under RUST are of values ranging between 35% and 50% from the corresponding values under ST.

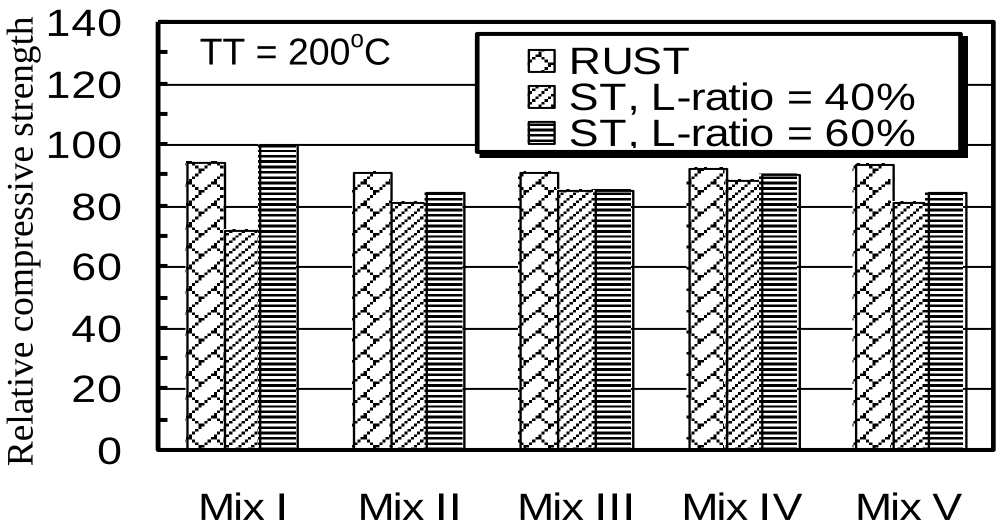

Fig. 7. Relative compressive strength for various mixes under RUST and ST conditions at TT = 200°C.

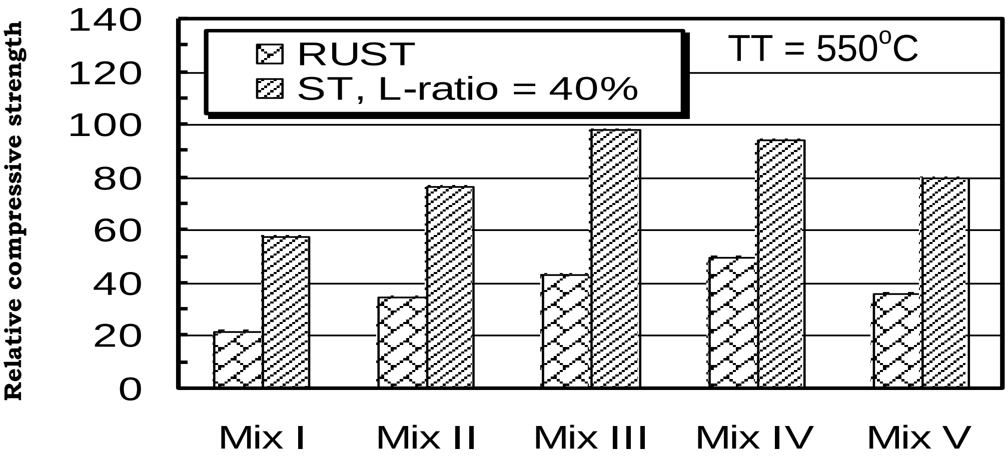

Fig. 8. Relative compressive strength for various mixes under RUST and ST conditions at TT = 550°C.

3.4. Effect of test methods

Figs. 9 to 11 demonstrate the effect of four thermo-mechanical test methods on the relative compressive strengths of the five concrete mixes: at TT of 200°C, and L-ratio of 40% in fig. 9, at TT of 200°C and L-ratio of 60% in fig 10, and finally at TT of 550°C at L-ratio of 40% in fig. 11. To explain the trends shown in figs 9 to 11 we must remember the forces struggling together to give these results which are. a) Physico-chemical stresses which may supply the un-hydrated cement particles with the required activation to enforce its hydration; b) Chemical stresses due to the effect of chemical decomposition or composition of aggregate and cement paste; c) Thermal stresses due to the differential thermal expansion between the concrete compositions; d) Mechanical stresses due to loading during heating.

To make a comparison between tests results, we will consider RUST results as abase. At temperature of 200°C the effect of chemical stresses is negligible. At 200°C, test results indicate that testing under UST conditions results in the lowest relative compressive strengths for the five mixes compared with other test methods as shown in figs 9 and 10. This may be due to the effect of thermal expansion stresses which limits the activation of the physico-chemical forces in the enforcement of the un-hydrated cement particles. The results under UST is also less than those under RUST conditions. The difference between both tests is that cooling of RUST specimens decreases the negative effect of thermal stresses with the continuation of water evaporation until 80°C. On the other hand, the RST gave relative compressive strength greater than those of the UST but still less than the RUST. This can be attributed to the contribution of the mechanical stresses due to loading during heating. The mechanical stresses create a micro cracks in the matrix and increase the opening displacement of the pre-existing cracks. These cracks or cavities decrease the effect of thermal expansion and act as tunnels allowing for the evaporation of water to enforce the hydration of the un-hydrated cement particles. When the specimens were cooled, the effect of thermal stresses is diminished but the cracks inside the samples are still exist which decrease the compressive strength when the specimens are loaded to fracture. With increasing, the load ratio from 40% to 60% the risk of crack occurrence increases and thus decreasing the relative compressive strength in the samples as shown in fig. 10. This assures the last explanation. The relative compressive strengths for the five mixes measured under the ST conditions are the highest among the others loaded and heated inside furnace. This may be due to the continuity of the mechanical stresses, loading during heating until fracture which creates spaces having a capacity to absorb the thermal expansion and help for the evaporation of water to enforce cement particles hydration as physico-mechanical force.

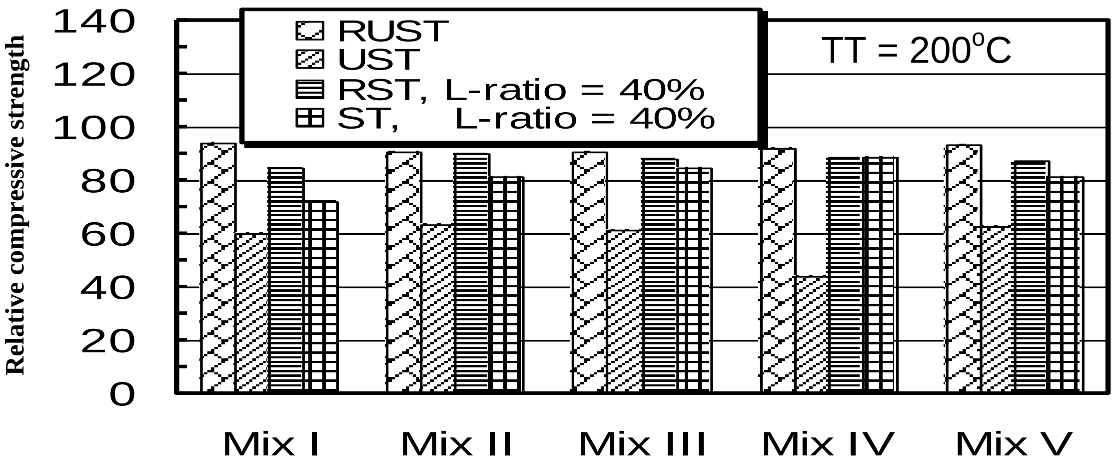

Fig. 9. Comparison between relative compressive strengths measured under different test methods at TT of 200°C and L-ratio of 40%.

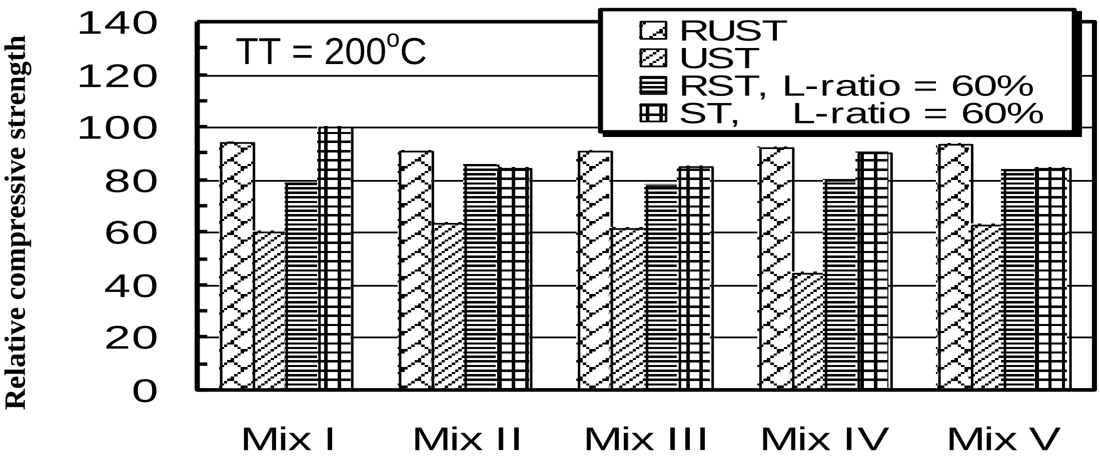

Fig. 10. Comparison between relative compressive strengths measured under different test methods at TT of 200°C and L-ratio of 60%.

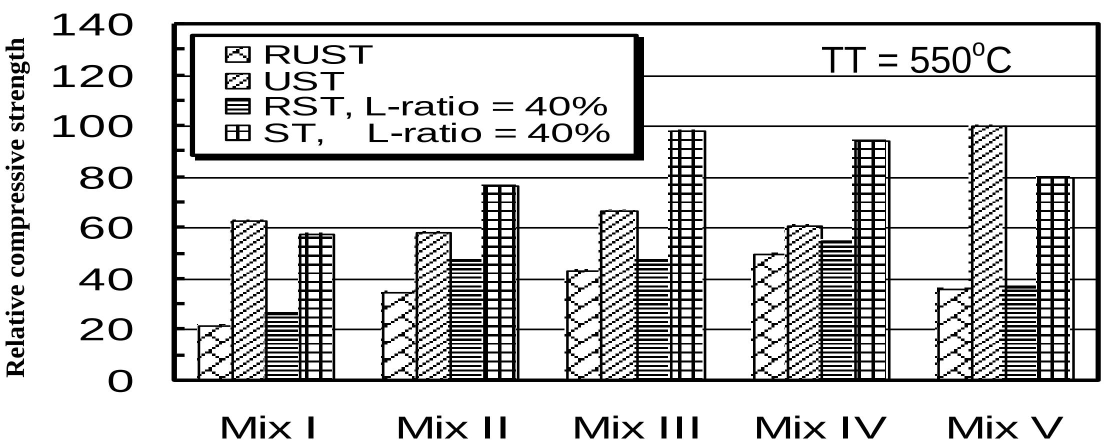

Fig. 11. Comparison between relative compressive strengths measured under different test methods at TT of 550°C and L-ratio of 40%.

At 550°C, the variation in the results of the relative compressive strengths shown in fig 11 illustrates that the struggle between the previous mentioned forces or stresses is completely different from those at 200°C. At this TT, 550°C, the chemical process which has not any contribution in strength gain or loss at 200°C, plays the main factor in controlling concrete strength. Above L-ratio of 40%, mechanical forces increase the risk of failure. The effect of physico-chemical forces, thermal force and mechanical one is diminished compared with the effect of chemical action at 550°C. This is clear from the comparison between the relative compressive strengths of the specimens fractured inside furnace, ST and UST, with those fractured outside the furnace, RST and RUST.

4. Conclusions

The results of the present investigation support the following conclusions:

At temperature of 200°C or 550°C, high strength concrete recorded the longest life when it loaded by 80% of the room temperature ultimate load, while normal strength concrete made of gravel as coarse aggregate and light weight concrete gave the smallest life time under these loading conditions. Under load ratio of 60%, mixtures of light weight concrete recorded the longest life time and this is because this load ratio may be not large enough to cause mechanical damage in concrete.

Increasing the load ratio from 40% to 60% at target temperature of 200°C under stressed test conditions decreased the reduction in the measured relative compressive strengths and this enhancement increased in the case of aggregates with high coefficient of thermal expansion. At target temperature of 550°C under this test, increasing the load ratio above 40% strongly increases the risk of strength reduction.

At high temperature of 550°C and loading during heating by 40% from the maximum load of the unheated specimens, concretes fractured inside the furnace recorded higher relative strengths compared to those fractured outside furnace after cooling.

Testing following the sequence of residual unstressed test conditions at target temperature of 500°C resulted in the lowest relative compressive strengths for the different concrete mixes. The highest relative compressive strengths under this heating condition were recorded when testing followed the sequence of stressed test at load ratio of 40% for almost all mixes.

The chemical reaction between free lime results from the decomposition of cement components with the moisture or CO2 from the surrounding atmosphere at 550°C is the main factor control the strength level of concrete subjected to this high temperature and cooled outside the furnace.

Under loaded tests conditions, loading of concrete by 60% during heating from the maximum load of the unheated specimens can be a safe load at low temperatures up to 200°C while above 200 °C the design load must not exceed 40% of the maximum load of the unheated specimens.

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