

Influence of Limestone Powder as Partial Replacement of Cement on Concrete and the Effect of High Temperature on It

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Abstract

In the recent years, the uses of the binding materials of different types in addition to cement become very wide in the product of concrete as blending of portland cement with limestone, so it is necessary to investigate the influence of the binder material on the concrete properties. In order to assess the performance of this type of concrete, it is important to understand the changes in the concrete properties especially in case of exposure to elevated temperature.

This paper summarize and discuss the effect of the limestone powder (CaCO_3) as a compensating material with cement on the compressive and tensile strength and discuss the effect of elevated temperature on this type of concrete.

Limestone powder (LP) was used as a compensating material with different ratio of cement include (0, 10, 15, 20, 25) %. Compressive and tensile strength were investigated before and after the exposure to high temperature including (200, 400, 600) °C.

The study show that limestone compensate changes in both compressive, and tensile strengths. Negative effects on the properties observed as the amount of limestone exceeds 15% of the cement weight. After the exposure to high temperature the results show a drop in compressive and tensile strengths in a different form.

Key words: Limestone powder; elevated temperature

تأثير مسحوق الجير كبديل جزئي من الإسمنت على الخرسانة ومفعول درجة الحرارة العالية عليها

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الخلاصة

في السنوات الاخيرة، أصبح إنتاج الخرسانة باستخدام مواد رابطة مع الاسمنت شائعا كالاسمنت المستبدل جزئيا مع مسحوق الجير، فأصبح من الضروري معرفة تأثير هذه المواد ونوعها على خصائص الخرسانة ومن أجل تقييم أدائها فمن المهم معرفة التغييرات التي يمكن ان تحدث فيها خصوصا عند تعرضها للحرارة العالية. أشتمل البحث على تلخيص ومناقشة تأثير مسحوق الجير (CaCO_3) كمادة تعويضية مع الاسمنت على مقاومة الانضغاط والشد وتأثير الحرارة العالية عليها، استخدم مسحوق الجير كمادة تعويضية مع الاسمنت بنسب مختلفة تضمنت (0، 10، 15، 20، 25) % تم دراسة مقاومة الشد والضغط بعد التعرض للحرارة العالية التي شملت (200، 400، 600) °C. أظهرت النتائج تأثير مسحوق الجير على مقاومتي الانضغاط والشد وبدأ التأثير السلبي عندما زادت النسبة عن 15 % كما ان التعرض للحرارة العالية أدى الى خفض مقاومتي الانضغاط والشد بنسب مختلفة للمزجات الخرسانية.

1. Introduction

Most cement plants consume much energy and produce a large amount of undesirable products, which affect the environment. In order to reduce energy consumption and CO2 emission and increase production, cement manufacturers are blending mineral additions such as slag, natural pozzolan, sand and limestone [Ghrici et al, 2007], limestone has been used in concrete production for the last 25 years, not only for the main purposes of lowering the costs and environmental load of cement production, but also to increase the concrete durability, more recently limestone is also used as a filler material to improve the workability and stability of fresh concrete and for a high flowable concrete, such as self-compacting concrete. [Esping, 2008]. Civil structures may expose to an elevated temperature or used for high temperature conditions, such as nuclear reactors, industrial furnaces and building exposed to accidental fire conditions. Therefore, fire resistance of structural elements has become an integral part of the design, the mechanical properties of all building materials at ambient and high temperature conditions are of interest and has, therefore, received special attention in the literatures. The fire resistance capacity of concrete is very complicated because not only the concrete is a composite material with components having different thermal characteristics, but also has properties that depend on moisture content and porosity [Shah et al, 1994], to determine the resistance of concrete samples exposed to high temperature, many test methods are used, three test methods are commonly referred in most experimental programs on the fire performance of concretes. In unstressed residual strength test method, the specimen is heated without preload at a prescribed rate to the target temperature, which is maintained until a thermal steady state is reached within the specimen. The specimen is then allowed to cool, following a prescribed rate, to room temperature. Load or strain is applied at room temperature until the specimen fails [Phan, 1996]. Unstressed residual strength test method was used in this study. In this paper, the characteristics of four different conventional concretes of different LP partial replacement of cement in fresh and hard concrete subjected to high temperatures up to 600°C were experimentally investigated, these characteristics are very important for the safe design of concrete and in the repair of concrete structure.

2. Experimental Details

2.1: Materials

The cement materials used in this study were ordinary Portland cement (PC) equivalent to Iraqi standard (IQS 5 – 1984); the properties of the cement are shown in Table (1).

Table (1) Properties of cement

Chemical composition*

Oxide Composition	SiO₂	Fe₂O₃	Al₂O₃	CaO	MgO	SO₃
Content (%)	20.6	2.68	5.32	62.7	2.8	2.27
Mineralogical components	C3S		C2S	C3A	C4AF	
Content (%)	41.53		27.97	9.57	8.15	

Mechanical properties

Age (day)	Compressive strength (MPa)	Tensile strength (MPa)
3	15.5	1.5
7	24.1	2.36

Physical properties

Setting	Initial	Final
time (min)	120	200

* Data are given by the manufacturer

The coarse aggregate used was a river rounded gravel with maximum aggregate size (12.5) mm equivalent to (B.S 812:1992) as shown in Fig. (1). A river sand with fineness modulus of 2.46 equivalent to (B.S 812:1992) was also used as a fine aggregate as shown in Fig. (2), city tap water was used in the mixes. LP was used in the mixes has a fineness of 0.15 μm .

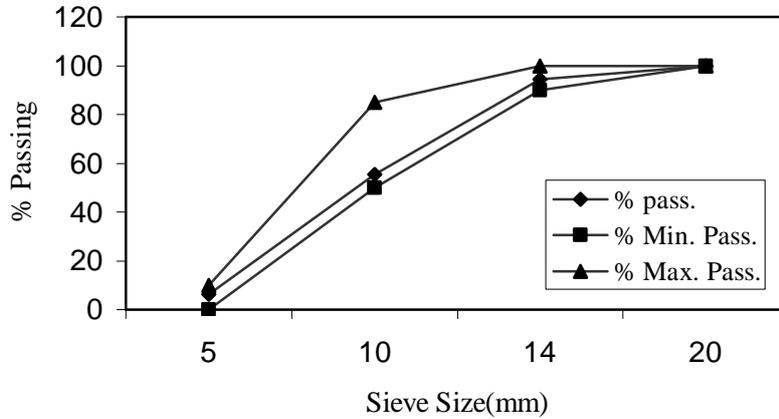


Fig. (1): Graduation of coarse aggregate

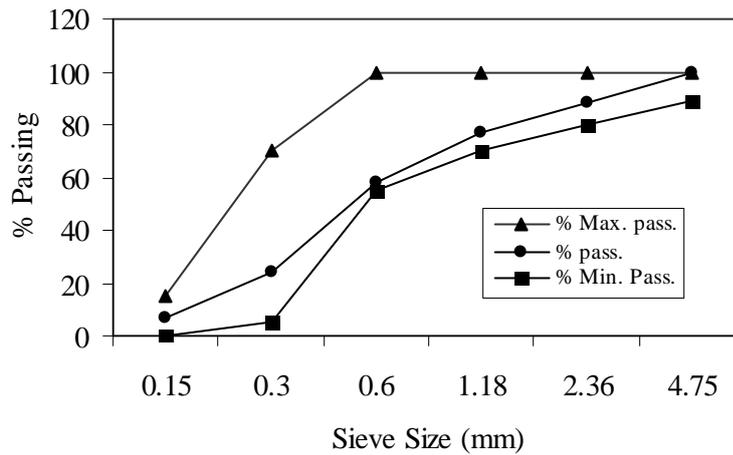


Fig. (2): Graduation of fine aggregate

2.2: Mix Proportioning

Five concrete mixes were prepared with LP as a cement compensating levels of (0, 10, 15, 20, 25) % by weight chosen after many trail mixes [Lothenbach et al, 2008]. All the concrete mixes were prepared at a water to binder (cement + LP) materials ratio of 0.46, the details of mix proportions (1 Binder: 1.75 Fine agg.: 2.9 Coarse agg /0.46 w/b) are shown in Table (2).

Table (2): Mix proportions (kg/m³)

mixture	cement	sand	gravel	water	LP
LP-0	390	682.5	1131	179.4	0
LP-10	351	682.5	1131	179.4	39
LP-15	331.5	682.5	1131	179.4	58.5
LP-20	312	682.5	1131	179.4	78
LP-25	292.5	682.5	1131	179.4	97.5

2.3: Specimen Preparation and Test

Concrete mixtures were made in a laboratory pan mixer. The aggregate, cement and LP were placed first and mixed at dry condition for about 2 min. After that, water was added, followed by another 2 min of mixing, slump was found according to (ASTM C143) to determine the concrete mixes workability. The batch was cast in twelve 100×100×100 mm³ cubic steel moulds and twelve 100×200 mm² cylinder steel moulds, then compacted using a vibration table. The specimen were cured in water for 14 days then cured at air dry condition at room temperature (20±1) °C for another 14 days. An electric furnace of maximum 600 °C was used. The specimens at age of 28 days were exposed to the desired temperatures for one hour without any load. Residual mechanical properties were determined including compressive and tensile strength according to (BS 1881: Part 116) and (ASTM C496) respectively. Initial setting time was also measured according to (ASTM C191).

3. Result and Discussion

3.1: Initial Setting Time and Slump

The effect of partial replacement of cement with LP on the initial setting time and slump are shown in Figs.(3,4) respectively (average of three samples), the initial setting time decreased to about 75 minute for the LP compensate with cement at amounts of (15,20)%, then increased to 90 minute at the maximum amount of compensating (25%). Apart from calcareous filler having a quite limited chemical interaction with hydration product, it has been shown that a chemical reaction of calcite CaCO₃ with C3A reactivity appears, yet the extent of calcareous filler chemical activity is generally admitted to be very limited [Hawkins et al, 2003]. As filler generally replaces cement there is a dilution effect, the cement paste amount decrease [Lawrence et al, 2005], these affected on time of initial setting.

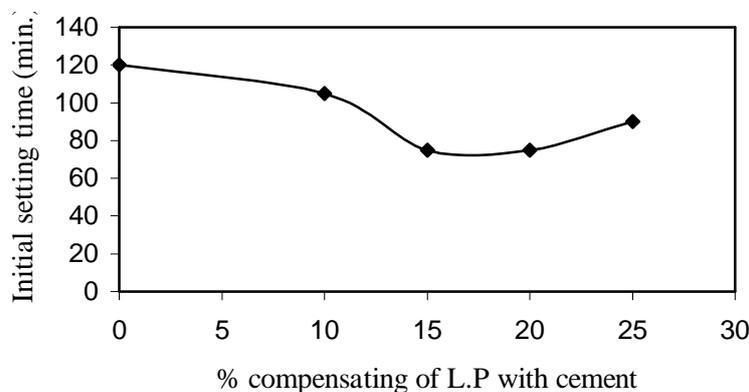


Fig (3): Effect of LP partial replacement with cement on in. setting time

Slump decrease to 72 mm with 10% compensating of cement with LP, and recovered to 75mm at amount 15% of compensating. The increasing of compensating of cement with LP, increase in slump ranged from 7% at 20% of compensating and expanded to 11% at amount 25% of compensating. Water is getting adsorbed at the surface of filler particles. As fillers specific surface is higher than that of sand, slump decrease due to adsorption phenomenon. As filler particles fill up voids, filler occupies the place of sand with smooth surface particles which reduced the inter particle friction that increase slump [Benachour et al, 2008].

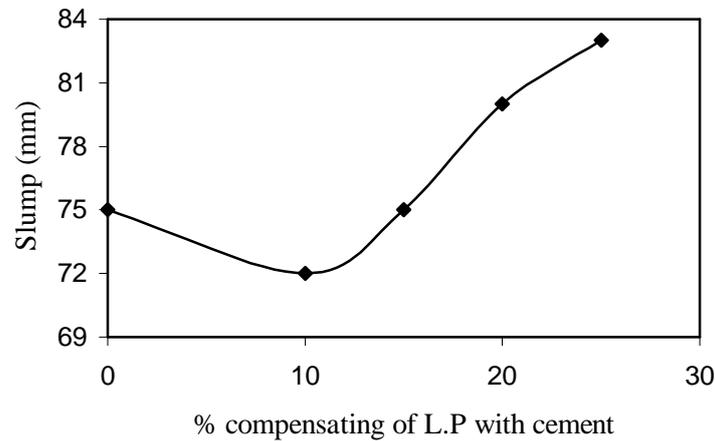
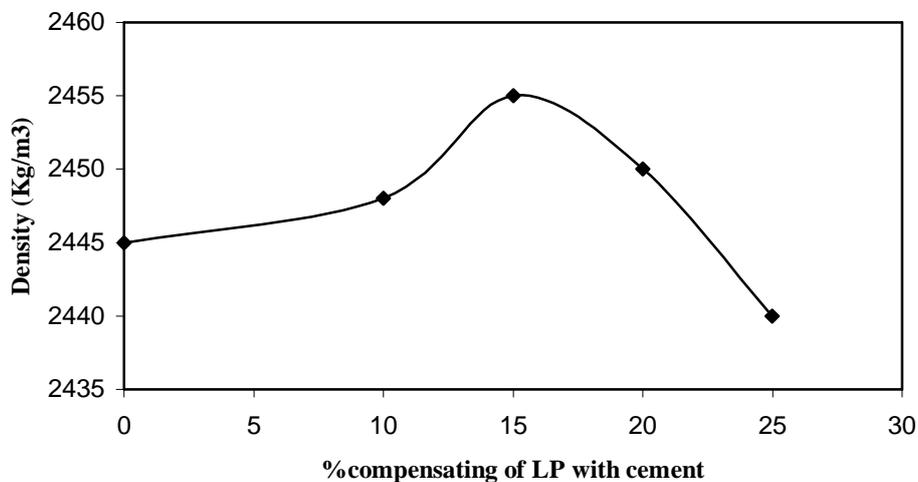


Fig (4): Effect of LP partial replacement with cement on slump

3.2: Concrete Density

Concrete is a porous material having discrete and interconnected pores of different sizes and shapes, the use of cement replacement materials result in achieving pore size refinement.

Fig(5) shows the variation of concrete density with the percent of LP as a partial replacement with cement, the density increase up to an optimal value at amount 15% compensating and then decrease for higher proportion. This is interpreted as filler powder first filling voids around sand grains, up to the optimum. For higher filler amounts, those voids being completely filled, filler powder then occupies the place of sand grains, hence diminishing sand proportion, and consequently the mix density [Bédérina et al, 2005]



Fig(5):Variation of density as a function of LP mass percentage.

When hardened concrete exposed to high temperature, loss of density due to loss of weight appears to take place due to evaporation of water from large capillaries and voids. Between 100°C and 600 °C loss of non evaporable water from gel pores and small capillary pores will take place [Ravindrarajah et al, 2002].

Fig.(6) shows the density losses at elevated temperature of the investigation mixtures of the cube specimens, concrete mixture compensating with 10% limestone powder act like normal concrete in density lost but more loss in density at 600°C, other concrete mixtures compensating with limestone powder exhibit less density loss than the normal concrete this is so clear at 400°C and 600°C, this attributed to the lower porosity of concrete mixtures compensating with limestone powder than normal concrete [Lothenbach et al,2008].

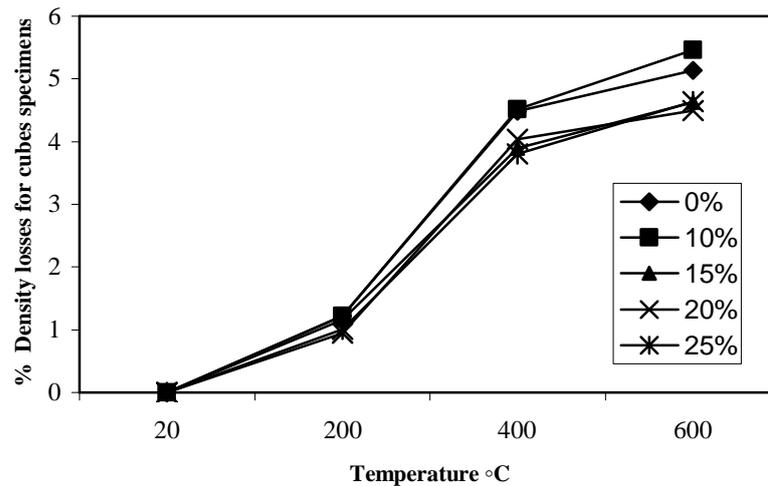


Fig (6) Density losses of concrete cube specimens

3.2: Compressive Strength

Fig.(7) shows the variation of compressive strength with % variation of LP for different temperature. For the unheated specimens, it can be seen that a 15 % compensating increase the compressive strength by 8.96% comparing with the 20 % compensating which resulted in less increase of 5.83% in the compressive strength, several combined effects may be called upon to explain strength maintenance. In presence of filler, the solid skeleton may be strengthened thanks to a more homogeneous distribution of smaller C–S–H crystals, finer pore structure, accelerated cement hydration [Moosberg-Bustnes et al, 2004], Moreover, the bond between cement paste and sand particles may be strengthened thanks to the reduction of the wall effect provided by the fine particles filling [Lawrence et al, 2005].

beyond an optimal value of LP addition (determined at 15% compensating in this study), the amount of fines increases so much that the cement paste is not able to coat all fine and coarse particles ,so drop in the reactive clinker component results in significant physical modifications of the material [Lothenbach et al,2008]. This phenomenon weakens the cement-to aggregate bond and hence leads to a loss in compressive strength for higher filler amounts than the optimal value [Celik et al, 1996], so 25% compensating resulted in decrease of 1.85% in the compressive strength.

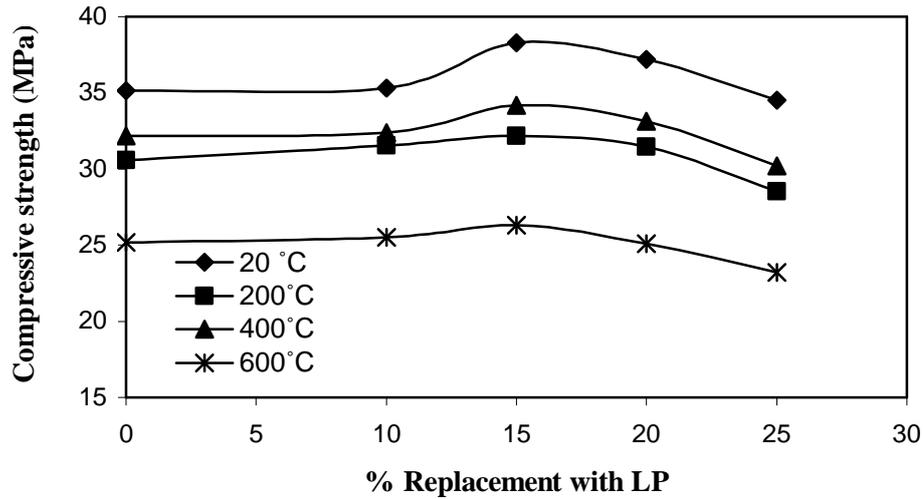


Fig (7): variation of compressive strength with replacement of LP

Fig.(8) shows the decrease in compressive strength with elevated temperature, it can be seen that all the concrete mixtures exhibited strength losses at 200°C then gained strength at 400 °C to a value nearly equal or more than 200 °C this may be attributed to some hydration of the cement paste at this temperature that did not occur at lower temperature. Above 400 °C all types of concrete loss their strength at faster rate, at this temperature the dehydration of the cement paste results in its gradual disintegration. Since the paste tends to shrink and aggregate expands at high temperature (different thermal expansion at temperature above 100 °C), the bond between the aggregate and the paste is weakened, thus reducing the strength of concrete.

The replacement of cement by limestone powder increase the decrease in compressive strength after exposure to elevated temperature this resulted by the dense micro structures which led to the build up of high internal pressure during heating [Poon et al, 2001].

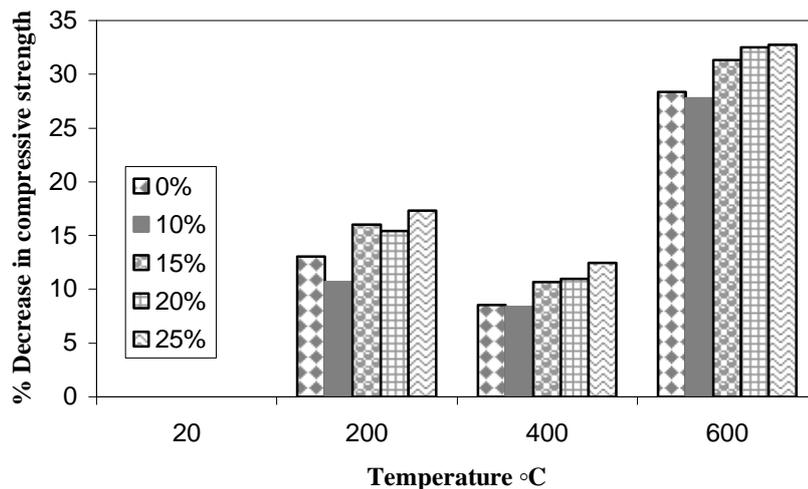


Fig (8) Decrease in compressive strength with temperature

3.3: Splitting Tensile Strength

Fig.(9) show the average tensile strength, it can be seen that the replacement of cement by limestone powder resulted in an increase of splitting tensile strength up to 15% then decrease.

For the unheated specimens, the increase in tensile strength expanded to be 13.62% at 15% compensating then decrease with the increase of LP replacement.

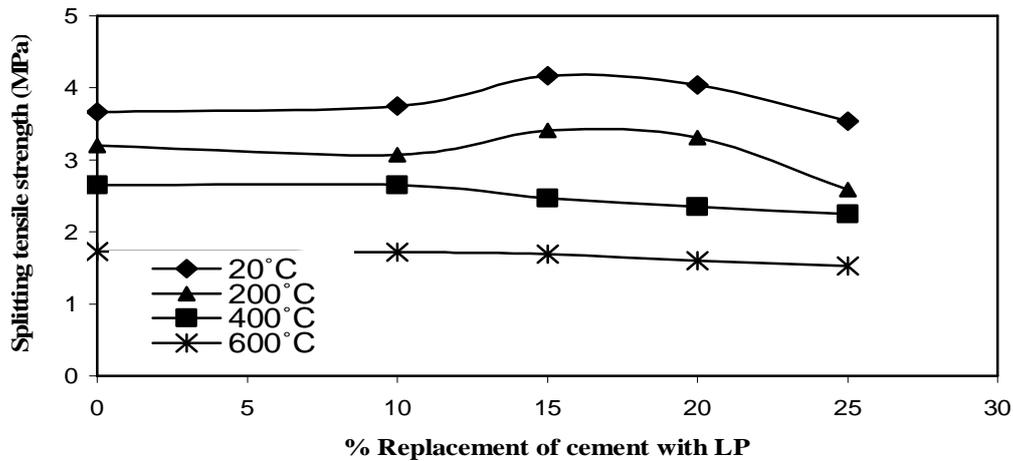


Fig (9): variation of splitting tensile strength with replacement of LP

Tensile strength showed significant losses with the increase in exposure temperature, this is so clear in Fig.(10), the residual tensile strength of concrete mixtures at 200 °C started from 87.19% for normal concrete and the residual decrease with the increase of compensating to be 73.2% at 25%, at 400 °C the residual tensile strength of normal concrete 72.2% then decrease when cement compensating by limestone powder at 20% to be 58.2%, no significant change in tensile strength at 600 °C, the residual tensile strength of normal concrete 47.1% while 20% compensating exhibit 40% residual strength.

The loss in tensile strength is considerably sharp, which is clearly different from the loss of compressive strength , this is because the tensile strength is more sensitive to macro- or non micro-scale cracks, which are caused by high temperature to concrete[Chan et al, 1999].

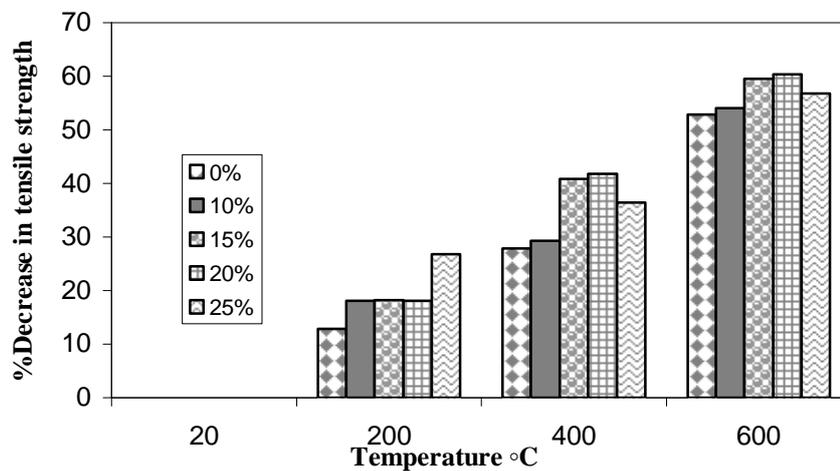


Fig (10): Decrease in tensile strength with temperature

4. Conclusions

This research study exhibit the feasibility of the use of LP as cement partial replacement in concrete mixes and studies the effect of elevated temperature on the compressive, and tensile strengths. The following conclusions could be extracted from this study:

1- LP offers a number of advantage for its use as cement compensating by enhance flow properties and increase compressive strength.

2-The slump of concrete relatively increase with higher values of the percentage of compensating of cement with LP.

3-Based on the results, it was observed that the compressive strength of concrete increase with the increase in LP compensating, concrete made with 15% LP compensating showed higher compressive strength.

4-In general, the compressive strength of LP concrete, like that of normal concrete, decrease with increasing temperature. At 400°C a higher value in the compressive strength is observed to that at 200 °C is observed.

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Appendix A:
Initial Setting time and slump

mix	In. setting time(min)	Slump(mm)
LPC-0	120	75
LPC-10	105	72
LPC-15	75	75
LPC-20	75	80
LPC-25	90	83

Compressive strength of investigated concrete (MPa)

Tem °C	% Replacement of cement with L.P				
	0%	10%	15%	20%	25%
20	35.15	35.32	38.3	37.2	34.5
200	30.57	31.55	32.17	31.47	28.53
400	32.15	32.37	34.2	33.12	30.2
600	25.18	25.51	26.3	25.1	23.2

Splitting tensile strength of investigated concrete (MPa)

Tem °C	% Replacement of cement with L.P				
	0%	10%	15%	20%	25%
20	3.67	3.75	4.17	4.04	3.54
200	3.2	3.07	3.41	3.31	2.59
400	2.65	2.65	2.47	2.35	2.25
600	1.73	1.72	1.69	1.6	1.53

The work was carried out at the University of Mosul