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EFFECT OF HIGH TEMPERATURE ON THE MECHANICAL STRENGTH OF BONE POWDER CONCRETE MORTAR

السلوك الميكانيكي للمونه المحتوية على بودرة العظم المطحون تحت درجات الحرارة العالية

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الملخص العربى

يتعرض البحث معمليا لتأثير درجات الحرارة العالية على مونة الخرسانة الأسمنتية المضاف إليها بودرة العظم المطحون كإضافة من وزن الأسمنت بنسب صفر, ٥%, ١٠%, ١٥%. حيث تم تعريض عينات المونة لدرجات حرارة مختلفة (درجة حرارة الغرفة ,١٠٠ , ٢٠٠, ٣٠٠, ٤٠٠, ٥٠٠, ٦٠٠ م°) وذلك لزمن قدره أربع ساعات. وتم اختبار العينات بعد تسخينها في الفرن للزمن المطلوب وتبريدها في الهواء عند درجة حرارة الغرفة. وتم التقييم على أساس مقاومتها للضغط منسوبة إلى مقاومة الضغط للعينات المناظرة والتي لم يتم تعريضها للحرارة وكذلك مقاومة الشد. وقد أوضحت النتائج أن كل من مقاومة الضغط والشد تقل بمقارنتها بالمقاومة عند درجة حرارة الغرفة (بدون تسخين) حتى درجة الحرارة ١٠٠ م° ثم تزداد مقاومة الضغط والشد حتى درجة الحرارة ٣٠٠ م° بمقارنتها بالمقاومة عند درجة حرارة ١٠٠ م° ثم تتناقص مقاومة الضغط وكذلك مقاومة الشد حتى درجة الحرارة ٦٠٠ م° بمقارنتها بالمقاومة عند درجة حرارة الغرفة. كما أوضحت النتائج أيضا أن أفضل نسبة إضافة لبودرة العظم والتي تعطى أعلى مقاومة نسبية هي ٥% في حالة مقاومة الضغط والشد. كما لوحظ ظهور شروخ على سطح العينات عند درجات الحرارة العالية(٦٠٠ م°) . كما أن الفقد في الوزن يزيد بزيادة درجة الحرارة وزيادة نسبة بودرة العظم المطحون.

ABSTRACT

When building materials are subjected to fire and exposed to cooling, some changes may occur in their characteristics; such as phase transformation, weight loss, aggregate-cement bond, etc., which directly affects on its chemical stability and mechanical properties. The effect of high temperature on the compressive and tensile strengths of concrete mortar premixed with bone powder (B.P.) as an addition as weight percent of cement was experimentally investigated. The percentages additions of bone powder were 0% 5%, 10% and 15%. 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, 500 and 600°C. After reaching to the desired target temperature, the specimens were hold at that temperature for 4 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. Addition of bone powder for concrete mortar by 5% recorded the highest relative compressive and tensile strength compared to other addition ratios. The mass loss increased with increasing temperature up to 600°C and B.P.%. In addition, at temperature of 600°C, cracks appeared on the surface of specimens.

KEY WORDS: Bone powder, Mortar, High Temperature, Compressive strength, Tensile strength.

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INTRODUCTION

Waste utilization is an attractive alternative to disposal in that disposal cost and potential pollution problems are reduced or even eliminated along with the achievement of resource conservation. Nevertheless, the utilization strategy must be coupled with environmental and energy considerations to use available materials most efficiently. Bone meal is a mixture of crushed and coarsely ground bones that is used as an organic fertilizer for plants and in animal feed. As a fertilizer, bone meal is primarily used as a source of phosphorus. Bone meal is used as a supplement for calcium and phosphorus. It is composed of finely crushed, processed bone, usually from cattle but sometimes also from horses. Bone marrow may also be added to the product. Calcium in bone meal occurs as a calcium phosphate compound known as hydroxyapatite or hydroxylapatite. Hydroxyapatite is an inorganic compound found in the matrix of bone and the teeth; it confers rigidity to these structures. The formula of hydroxyapatite is $(Ca_3 (PO_4)_2)_3$ $Ca(OH)_2$ or $Ca_{10} (PO4)_6 (OH)_2$ [1].

Since late 2000 [2] in France and early 2001 [3] in the rest of Europe, low-risk Meat and bone meal (MBM) is no longer used in animal feeds. Other applications including MBM have been proposed, such as phenolic concrete blocks (without Portland cement), composed of 85% raw MBM and 15% phenolic resin acting as the cementing part [4]. According to its inventors, the material was 30% cheaper than traditional concrete and offered adequate modeling, strength and fire resistance properties [5]. At present, all MBM ash goes to landfill, but there is potential for it to be used in various types of concrete such as mass concrete, dry lean bases and sub-bases for road construction and for building blocks. The ash as supplied is fine and there is potential for it to be used at substitution levels of up to 10% by weight of normal concrete or up to 20% of lean concretes road CBM or building blocks [6]. Meat and bone meal bottom ash has the physical aspect of a fine sand, with a grading between 0 and 2 mm and a mean diameter of 0.4 The bulk density of MBM-BA is around 900 kg/m^3, much lower than that of the sand commonly used in cement-based materials (1500 kg/m^3). The average density of the particles is 2900 kg/m^3. The external specific area, calculated from the density and the particle size distribution (considering cylindrical particles), is about 3 m^2/g. Optical and electronic microscopy shows that MBM-BA is composed of irregular particles. Many grains present a porous texture; The BET method gives a specific area of 3000 m^2/kg, which is a thousand times higher than the value calculated using the particle size distribution. This significant difference is related to a large open porosity of the grains, leading to water absorption of 11%, a very high value compared to normalized siliceous sand (less than 1%). [7].

Martin and Ludmann [8] presented the effect of MBM-BA on the consistency and compressive strength of cement-based materials. Increasing proportions of MBM-BA (17%, 33%, 50% and 100%) were used as replacement of siliceous sand in mortars. The water/cement ratios were fixed at 0.50 and 0.85 (total replacement of sand). The results showed that MBM-BA had the physical and mechanical characteristics of sand. It has low friability but it had high water absorption, which led to the use of a super plasticizer, which leads to a recommended use of less than 30% MBM-BA as sand replacement in mortars. The compressive strength of mortar containing 17% of MBM-BA is similar to that of a reference mortar. Regarding these preliminary results, lead us to believe that low-risk MBM-BA could be used in cement-based materials and present a promising way of reusing this residue.

Recent references have pointed to opportunities for the development of adhesives and sound or thermal insulation from meat and bone meal. [9-11]. Hertz [12] indicated that silica fume concrete is highly prone to spelling and cracking at elevated temperatures. He prepared a special 170-MPa concrete containing 14 – 20% silica fume. Five of the fifteen 100×200-mm cylinders exploded when heated to 650°C. The test results indicated that on average, the residual compressive strength of silica fume concrete increased with temperature up to 350°C and then decreased sharply. The engineering properties of construction materials at elevated temperature are very important for high rise buildings. Of all construction materials, concrete is one of the most resistant to heat and fire. Experience has shown that concrete structures are more likely to remain standing through a fire than are structures made of other materials. Unlike wood, concrete does not burn and unlike steel [13]. Dale [14] reported that a significant mass loss is observed in the temperature range from 100°C to 250°C corresponding to loss of water from the CSH gel and aluminate hydrate products such as ettringite. Second significant mass loss occurs in the temperature range 450°C to 550°C, corresponding to loss of water from the calcium hydroxide (CH). This loss is observed in condensed silica-fume concert, because the CH formed pozzolanic CSH, which loses its water in the same temperature range as the primary CSH.

Until now there is no any study related to the effect of high temperature on mechanical strength of bone powder concrete mortar. In the present investigation bone powder (B.P.) was used as an addition by weight of cement (0%, 5%, 10% and 15%). All mortars samples were exposed to six different temperatures of 100, 200, 300, 400, 500 and 600°C for 4 hours soaking time with heating at an average rate of 10°C/min. The weight loss and residual compressive and tensile strengths due to exposure to those high temperatures were experimentally investigated in the present work.

EXPERIMENTAL PROGRAMMED

The cement used in mortar mixes was ordinary Portland cement (OPC) according to E.S. 373/199. 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 2.49. Bone powder (B.P.) used in this research as shown in photo. 1 was obtained from crushing of animal bones by using Water wheel – powered bone crusher. The chemical composition and physical properties of bone powder are given in Tables 2, 3. Bone powders were used in cement mortar mixes as an addition with percentages of 0, 5, 10 and 15% by weight of cement content. Cubes 70×70×70 mms were prepared for testing under static compression. Cylinders of 75 mms diameter and 150 mms 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 bone powder were mixed in the dry state 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. The specimens were then surface dried and placed in a high temperature furnace. The drying process is necessary to minimize the risk of explosion of the concrete specimens when they are directly subjected to high temperatures within the furnace.

After drying, the specimens were exposed to temperatures of 100, 200, 300, 400, 500 and 600°C and kept at that temperature for 4 hours in the furnace with an average heating rate of 10°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 1000 kN capacity. Cracking of specimens after heating were recorded and observed.

RESULTS AND DISCUSSIONS

Mass Loss

The mass losses percentage were estimated as the difference in the mass between the unheated and heated specimens to that of the unheated specimens and then multiplied by 100. The effect of high-elevated temperatures on the mass loss percentage of the four mortar mixtures considered (M_{B0}, M_{B5}, M_{B10} and M_{B15}) are illustrated in Fig.1. In the figure, the mass loss was represented against the target temperatures. All mixtures demonstrated an increase in the relative mass loss with increasing temperature. The loss rate is fast at the first stages of heating up to temperature of 200°C. The mix of bone powder percentage equal to 15% recorded the highest relative mass loss while that of 0% bone powder recoded the lowest relative mass loss. The specimens, which contained 15% B.P., started to crack at 500°C and continued to crack severely as the temperature increased. This result clearly indicates that higher water evaporation leads to more weight loss due to heating. The loss rate is high at low temperatures up to 200°C, after that it stabilized before increasing again above 500°C. When the heating temperature is under 200°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°C, the weight loss is mainly caused by gradual evaporation of gel water and the concrete undergoes a mix physico-chemical process. For a temperature over 400°C, the weight loss is mainly caused by evaporation of chemically combined water (dehydration) and decomposition, so the concrete undergoes a chemical process [15].

Figure 2 demonstrates the effect of B.P. percentage on the relative mass losses of mortar specimens at different high temperatures. The figure clearly indicates an increase in the mass loss with increasing bone powder content. These losses are increased with increasing target temperatures. The cement mortar mixtures with different bone powder percentages at temperature of 600°C recorded the highest relative mass loss while that at 100°C recoded the lowest relative mass loss.

Compressive Strength

The effect of high temperature on the relative compressive strength of concrete mortar specimens for B.P.,% equal to 0%, 5%, 10% and 15% are shown in Figs. (3-a, b, c, d, and e,). The relative compressive strength here is defined as follows:

Relative compressive strength = $[\sigma_{CH}/\sigma_{CRT}] \times 100$

Where σ_{CH} is the compressive strength of the specimen that exposed to the desired target temperature and σ_{CRT} is the corresponding compressive strength of the unheated specimens at room temperature at the same B.P.,%. Figures (3-a to e) indicated that the compressive strength for all B.P.% decreased compared to that measured at room temperature (without heating). Initially, as the temperature increased to 100°C, the average relative compressive strength for all B.P.% decreased compared to heat measured at room temperature (without heating) by a value 8%. With further increase in temperature up to 300°C, the average relative compressive strength increased compared to that measured at 100°C by 3% and 6% for target temperatures of respectively 200°C and 300°C. Above temperature of 300°C, the compressive strength markedly decreased compared to heat measured at 100°C by a value 9, 17 and 54% for target temperatures equal to 400, 500 and 600°C respectively. It is clear also that, all mortar mixes exposed to high temperatures suffered a significant depression in compressive strength compared to that measured at room temperature. The significant strength loss after 500°C is mainly due to the loss of water from the free calcium hydroxide (CH) (results from cement hydration), leaving calcium oxide (quick lime). This calcium oxide absorbs water from the surrounded atmosphere as the specimen leaved to cool. Thus it is re-hydrated to CH or reacts with atmospheric CO_2 resulting in the formation of calcium carbonate ($CaCO_3$). These processes are accompanied by an expansion in the volume, which may disrupt the material [16, 17]. Thermal decomposition of some binding products such as Ca-sulphate-aluminate hydrate and calcium silicate hydrates may be also a reason for the higher reduction in the compressive strength at high temperature.

To explain the role of B.P.% on controlling the behavior of mortar at high temperature, the compressive strength of the heated mortar specimen with different B.P.% (σ_C) was divided to that with B.P.% equal to 0% (σ_{CO}), and the results at different temperatures are shown in Fig. 4. The effect of B.P % at different temperatures shows similar trends, i.e. an increase in the strength ratio as the B.P.% increases up to B.P.% =5% and after that it decreases at all temperature . Also it is clear that the strength ratio increases as the exposed temperature increases especially at temperatures of 500 and 600°C for B.P. % equal to 5%. As an example for B.P.% equal to 5%, the strength ratio reached 121.7% at 500°C and 116.3% at 600°C. The decrease in the strength with further increase in B.P added to the cement may be because by increasing the bone powder without the equivalent required amount of cement to achieve pozzolanic hydration, an adverse effect on the bond in the matrix is occurred.

Photo.2 shows the crack pattern of the concrete mortar specimens after exposed to temperature of 600°C for all B.P.%. A wide crack is observed on the specimen surface for B.P. % equal to 15% compared to a very narrow surface cracks in the case of B.P.% equal to 5%. In specimens heated previously at temperatures lower or equal to 400°C, cracks appear later than in specimens heated at temperatures greater than 400°C. However, the cracks in the former case grow very fast and a main diagonal crack can be seen clearly.

Tensile Strength

The effect of high temperature on the relative tensile strength of concrete mortar specimens fabricated with B.P.% equal to 0 %, 5%, 10% and 15% were shown in Figs. (5-a, b, c, d, and e). The relative tensile strength here is defined as follows:

Relative tensile strength = $[\sigma_{TH}/ \sigma_{TRT}] \times 100$

Where σ_{TH} is the tensile strength of the specimen that exposed to the desired target temperature and σ_{TRT} is the corresponding tensile strength of the unheated specimens at room temperature at the same B.P.%. Initially, as the temperature increased to 100°C, the average relative tensile strength for all B.P.% decreased compared to that measured at room temperature (without heating) by a value 9%. With further increase in temperature up to 300°C, the average relative tensile strength increased compared to that measured at 100°C by a value 2% and 6% for target temperatures of respectively 200 and 300°C. Above temperature of 300°C, the tensile strength markedly decreased compared to that measured at 100°C by a value 2.5, 11.7 and

48% for target temperatures equal to 400, 500 and 600°C respectively. It is clear also that, all mortar mixes exposed to fire suffered a significant depression in tensile strength compared to that measured at room temperature. As the temperature rises above 300°C, small part of the decomposed paste is re-sintered into clinker and recovers little binding capability. In addition, cement paste starts to shrink when heated above 300°C. Due to different rates of expansion, cracks may occur on the surface of the concrete mortar.

To explain the role of B.P.% on controlling the behavior of mortar at high temperature, the tensile strength of the heated mortar specimen with different B.P.% (σ_t) was divided to that with B.P.% equal to 0% (σ_{to}) at the different regimes of high temperatures including RT as shown in Fig. 6. The same trends shown in the compressive strengths were observed in the case of tensile strengths. For example an increase in the strength ratio is observed when the B.P.% increases up to B.P.% =5% and after that it decreases at all temperature. Also it is clear that the strength ratio increases as the exposed temperature increases especially at temperatures of 500 and 600°C for B.P.% equal to 5%. As an example for B.P. % equal to 5%, the strength ratio reached 128.8% and 127.8% at temperature equal to 500°C and 600°C respectively. The high temperature tends to change the mechanism of ettringite formation. Ettringite hydrates begin to dehydrate with this temperature range and ettringite ruptures and disintegrates. The decrease in volume of the hydrate phase and the coarsening of the pore structure of cement mortar are the main reasons influencing mechanical properties decrease at high temperature attack [18].

CONCLUSIONS

This paper investigated the effect of high-elevated temperatures on mass loss, the compressive and tensile strength of cement mortar incorporating grounded bone. The results of the work reached to the following conclusions:

1- All mortar mixes exposed to high temperature suffered a significant depression in compressive strength compared to heat measured at room temperature.

2- As the temperature increased to 100°C, the compressive and tensile strength for all B.P.% decreased compared to that measured at room temperature (without heating). With further increase in temperature up to 300°C, the compressive and tensile strength increased compared to heat measured at 100°C. Above temperature of 300°C, the compressive strength markedly decreased compared to heat measured at 100°C.

3- An increase in the compressive and tensile strength as the B.P. % increases up to B.P.% =5% and after that it decreases at all temperature. Also it is clear that the strength ratio increases as the exposed temperature increases especially at temperatures of 500 and 600°C for B.P.% equal to 5%.

4. The mass loss increased with increasing of temperature up to 600°C and B.P. %.

5- A wide crack is observed on the specimen surface for B.P.% equal to 15% compared to a very narrow surface cracks in the case of B.P.% equal to 5%.

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Table 1 Properties of the used OPC.

Property	Results	B.S. Limits
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	225	≥ 160
After 7 days	297	≥ 240
After 28 days	379	≥ 360

Table 2 Chemical composition of bone powder.

Constituent	CaO	SiO_2	Al_2O_3	P_2O_5	Na_2O	MgO	K_2O	LOI
Content, %	52.45	1.34	0.35	36.85	1.6	1.3	0.3	1.2

Table 3 Physical properties of bone powder.

Property	Value
Specific gravity	1.85
Unit weight kg/m^3	690
Finness, %	7
Color	Light-yellow

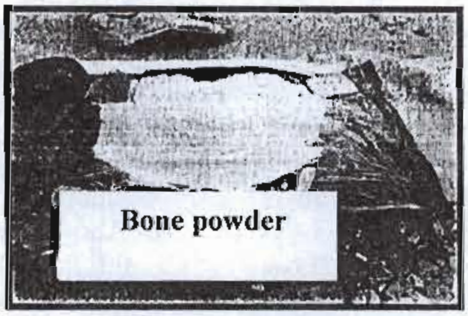

Photo 1: Bone powder

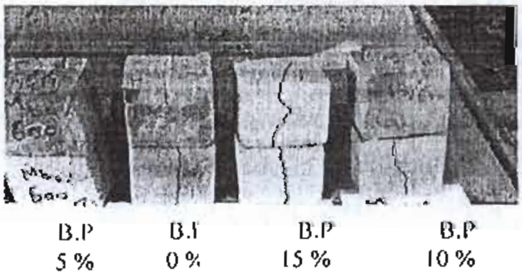

Photo 2: Crack pattern of mortar specimens after heating to 600°C.

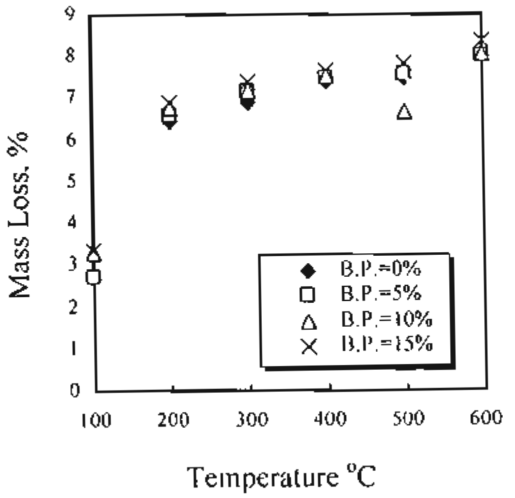

Fig. 1: Mass loss % vs temperature °C for different bone powder %.

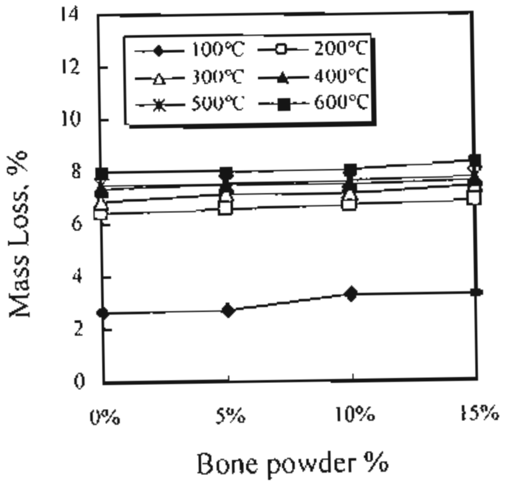

Fig. 2: Mass loss % vs bone powder % for different temperature °C.

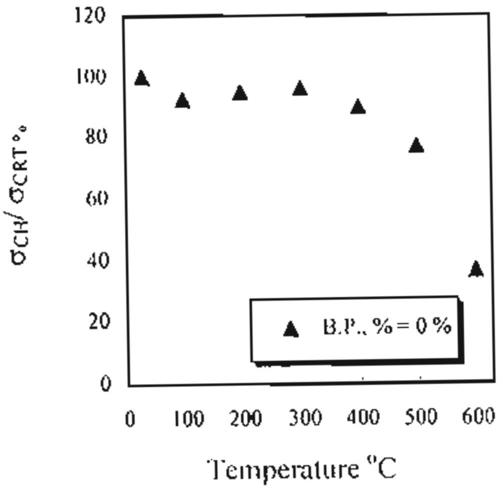

Fig. 3-a: Relative compressive strength vs temperature °C for B.P.%=0.

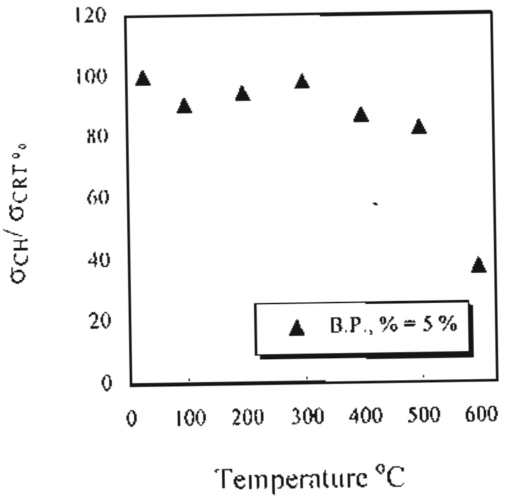

Fig. 3-b: Relative compressive strength vs temperature °C for B.P.%=5.

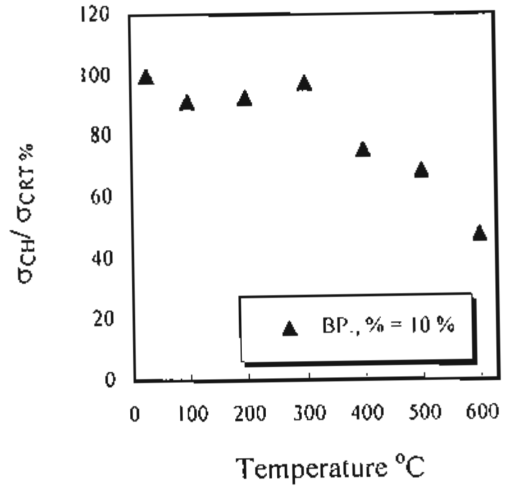

Fig. 3-c: Relative compressive strength vs temperature °C for B.P.%=10.

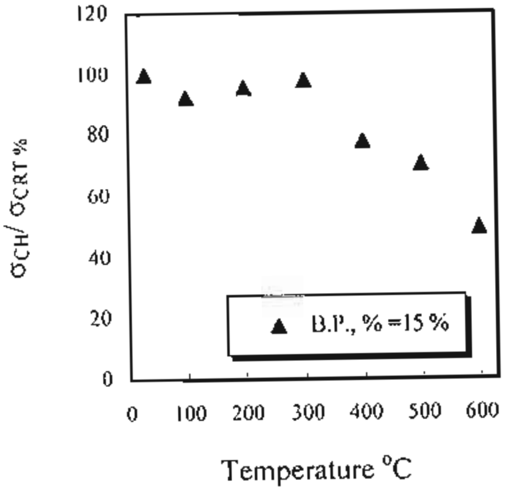

Fig. 3-d: Relative compressive strength vs temperature °C for B.P.%=15.

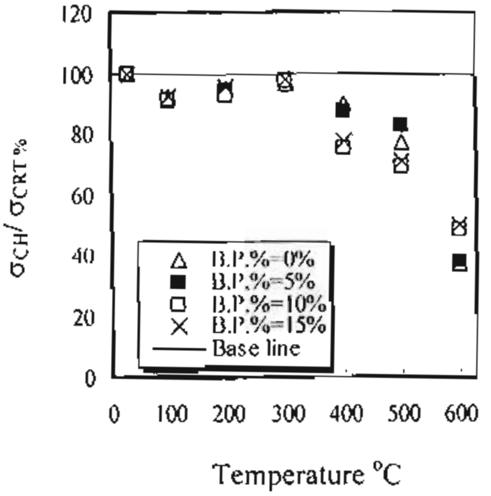

Fig. 3-e: Relative compressive strength vs temperature °C for different B.P.%.

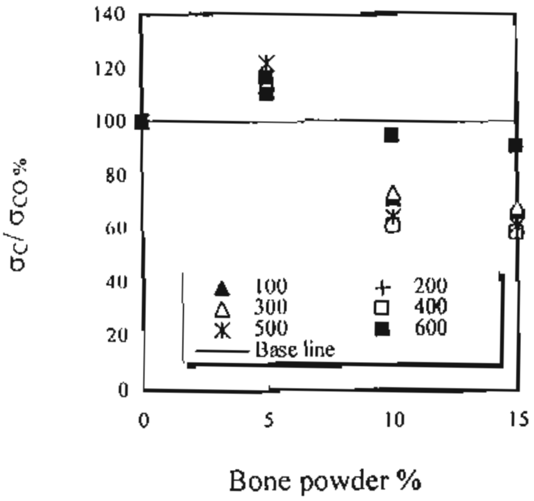

Fig. 4: Relative compressive strength vs bone powder % for different temperatures.

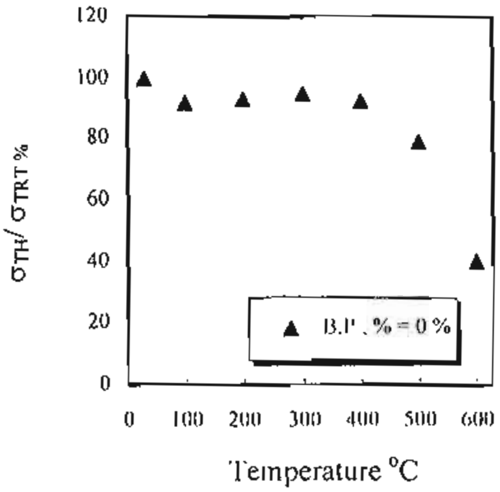

Fig. 5-a: Relative tensile strength vs temperature °C for B.P.%=0.

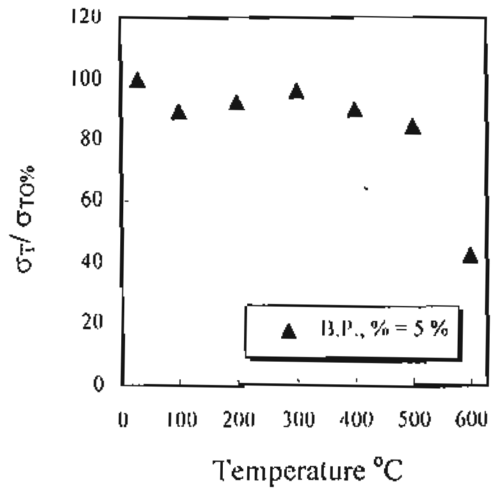

Fig. 5-b: Relative tensile strength vs temperature °C for B.P.%=5.

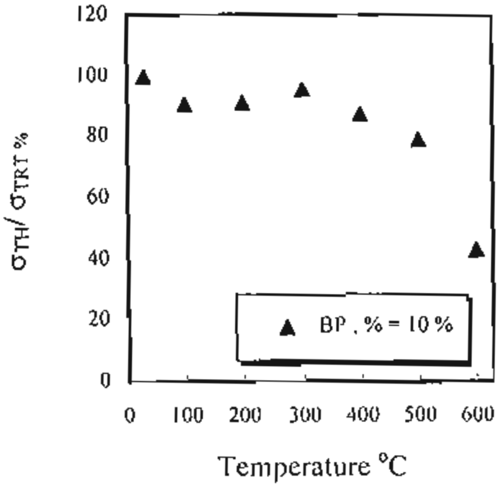

Fig. 5-c: Relative tensile strength vs temperature °C for B.P.%=10.

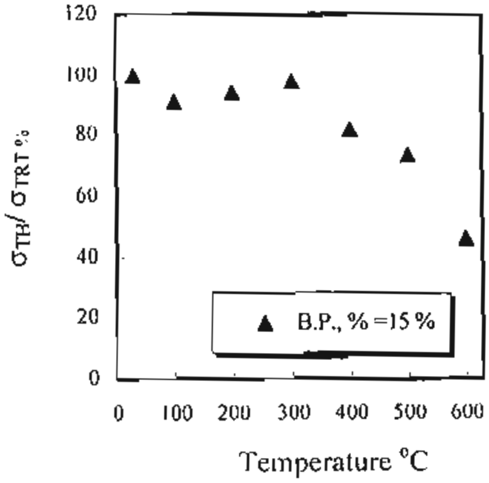

Fig. 5-d: Relative tensile strength vs temperature °C for B.P.%=15.

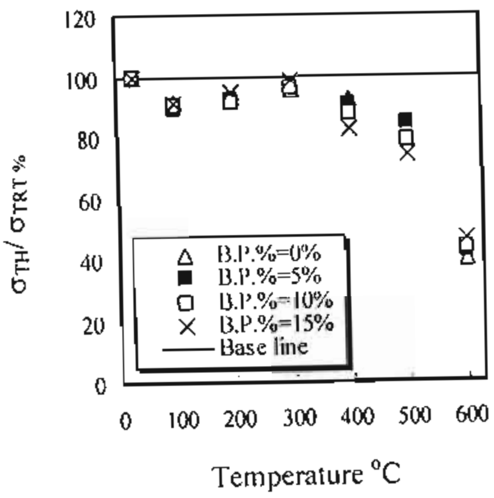

Fig. 5-e: Relative tensile strength vs temperature °C for different B.P.%.

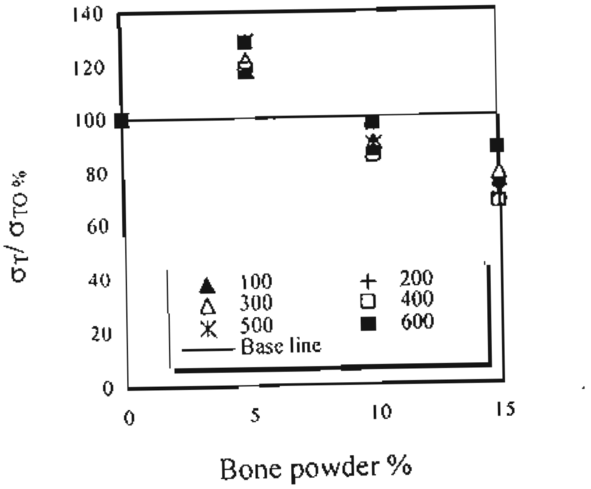

Fig. 6: Relative tensile strength vs bone powder % for different Temperatures.