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(54) **Method of cleavage of stone material**

Verfahren zur Spaltung von Steinmaterial

Méthode de clivage de matériau en pierre

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- **DATABASE WPI Section PQ, Week 197814 Derwent Publications Ltd., London, GB; Class P64, AN 1978-C8543A XP002353308 -& SU 527 294 A (LENINGRAD PLEKHANOV MINE) 13 July 1977 (1977-07-13)**
- **PATENT ABSTRACTS OF JAPAN vol. 1996, no. 02, 29 February 1996 (1996-02-29) -& JP 07 266327 A (MATSUSHITA ELECTRIC WORKS LTD), 17 October 1995 (1995-10-17)**

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Description

[0001] The present invention relates to a method for the splitting or cleavage of stone material in the form of slabs, amongst which may be mentioned porphyry, Lucerne stone and Lessinia or Prun stone, but not only these. Such materials are generally used as building material in the form of slabs, in particular, for the construction of wall coatings, kerbs for pavements, tracks for cobblestone pavings, and floorings or coatings and facings in general.

[0002] The stone materials in the form of slabs of interest for the present invention are ignimbritic effusive products. Ignimbrite is a rock that is formed following upon.deposition of pyroclastic material that is expelled together with gas from volcanic structures in the form of *nuée ardente,* which during cooling gives rise to a suspension containing solid material (crystals, lapilli, ash, pumices, etc.) and liquid material (lava). The pyroclastic material, during its flow and then during its cooling, consolidates and acquires a typical pseudofluidal appearance, assuming, that is, a specific sub-vertical ribbon-shaped appearance characterized by parallel stratifications. Macroscopically ignimbrites present very fractured crystals basically of quartz and feldspar, elongated pieces of pumices or lapilli in a generally vitreous pseudofluidal matrix. The colour ranges from light grey to pale pink and to light red.

[0003] Use of these stone materials in the form of slabs in the building sector is enabled by the possibility of producing slabs of stone by manually performing a cleavage of the starting block of stone. Cleavage can take place because the natural stratifications of these materials correspond to planes of discontinuity with low energy content, the presence of which enables splitting/cleavage of the block of stone, which, as has already been said, is still even today performed manually.

[0004] The aim of the present invention is to provide a method for the splitting or cleavage of stone materials in the form of slabs which can be implemented industrially and does not call for the manual activity of a skilled craftsman.

[0005] This aim is achieved by a method comprising the combination of features of independent claim 1.

[0006] The proposed technical solution envisages carrying out cleavage by means of a thermal treatment of the starting stone material. In particular, the stone material is heated to a high temperature, and is then cooled rapidly, in conditions such as to prevent thermal shock in the stone material, a shock which could be followed by the partial or even complete shattering of the stone material itself.

[0007] Preferred embodiments of the method according to the invention are disclosed by the dependent claims..

[0008] The invention will now be described in detail, purely by way of non-limiting example, with reference to the annexed plate of drawings, wherein:

- Figure 1 presents the graph of the temperature within a block of porphyry as a function of the distance from the surface;
- Figure 2 represents the orientation of the cartesian axes and of the reference block;
- Figure 3 presents the graph of the stresses σ_Y within the specimen along the axis X;
- Figure 4 represents the profile of the stresses σY for different initial temperatures of treatment of the specimen;
- Figure 5 represents the relation between maximum temperature applied and maximum surface stress generated following upon cooling of the specimen;
- Figure 6 represents the graph of the stresses σ_Y within the core of the specimen in the direction X;
- Figure 7 illustrates the effect of the geometry of the specimen on the stress σ_Y; and
- Figure 8 illustrates the effect of the dimensions of the specimen on the stress σ_Y.

Preliminary theoretical treatment

[0009] The technical problem of cleavage of stone materials along their planes, of discontinuity was initially faced theoretically so as to determine the variables involved and select their most appropriate values to achieve the desired technical result, i.e., the splitting/cleavage of the stone material along its planes of discontinuity - also defined as slip planes - without shattering of the stone material.

[0010] Initially, some evaluations were made regarding the stay time in the furnace for heating the starting stone material, the maximum temperature to which the material can be heated, and the genesis of the stresses in the specimen during cooling.

[0011] The specimen virtually used for this theoretical treatment was a parallelepiped/slab of stone material with variable width, length and thickness of the slabs.

Stay time in the furnace for homogenization of the temperature

[0012] For calculation of the heating times recourse was had to one-dimensional theory. In this approximation, the transmission of heat is given by the formula:

$$T = T_s + (T_i - T_s)\,erf\left(\frac{x}{2\sqrt{at}}\right) \qquad (0.1)$$

where T is the temperature at the point x, T_s is the surface temperature, T_i is the initial temperature of the specimen, t is the stay time in the furnace and $a = \frac{\lambda}{\rho C}$ the thermal diffusivity, which, for the material forming the subject of the analysis; corresponds to 1.4 x 10^{-6} m^2/s.

[0013] With an initial temperature of the block of porphyry of approximately 25°C and an applied surface temperature of approximately 400°C, it was calculated that 7 - 8 hours are required for heating in the furnace to obtain a temperature equal to the one applied to the surface, i.e., approximately 400°C, at a depth of 10 cm from the surface.

[0014] In Figure 1, we can analyse the graph of the temperature as a function of the distance from the surface of the block of rock for a stay time in the furnace of approximately one hour, for two applied surface temperatures, 400°C and 250°C. It appears evident that, after one hour of heating, at the depth of 1 cm from the surface a sufficiently high temperature is reached, comparable to the surface temperature.

Maximum sustainable temperature

[0015] For the calculation of the temperature of thermal shock, i.e., the temperature beyond which the material breaks in a brittle way along any planes, considering the material isotropic where planes of discontinuity or slip planes are not present, the following formula was used:

$$\sigma_{st} = \frac{E\alpha}{1-\nu}(T_c - T_s) \qquad (0.2)$$

where σ_{st} is the strength of the material, T_c is the temperature within the core (Figure 2), T_s is the surface temperature, α is the coefficient of thermal expansion, and, finally, E and ν are the elastic modulus and Poisson's ratio, respectively.

[0016] The equation (0.2) is valid in the case of a slab and hence of a plane stress.

[0017] Considering that the fracture strength of the material under examination is approximately 22 MPa, Poisson's ratio ν is equal to 0.3, the coefficient of thermal expansion α is approximately 5.55 x 10^{-6} °C, if the surface temperature is 25°C, by applying the equation (0.2), a temperature within the core of the specimen of approximately 477°C is obtained, which causes thermal shock.

Genesis of the stresses in the specimen

[0018] In order to determine the stresses that are generated within the specimen during sudden cooling, some computer simulations were conducted, assuming water as reference fluid and Trentino porphyry as material.

[0019] The model considered simplifies the conditions of thermal exchange: heat exchange on the surface of the real specimen is of a convective type, whereas in the model a constant surface temperature is maintained.

[0020] The evaluation of the state of stress of the specimen immersed for 1 s in cold water (at a temperature of 20-25°C) reveals that the maximum generation of stress takes place instantaneously. In particular, it has been calculated that the stress in the direction Y (see Figure 2 for the orientation of the axes of the cartesian system, S_Y) is the greatest stress, and that it is precisely this stress that is responsible for cleavage of the specimen along the low-energy planes, which, in the tests reported herein, were perpendicular to said axis.

[0021] It was shown that the stress is maximum at the core and, for a specimen with a thickness of 15 cm, assumes a value of approximately 16.9 MPa. This value was calculated for a homogeneous temperature of 400°C within the specimen prior to cooling. The simulation enabled verification of the fact that at 400°C for the geometry tested no thermal shock occurred since the fracture strength of porphyry is approximately 22.5 $\pm$ 3.3 MPa.

[0022] Also the stresses generated throughout the cross section of the specimen were calculated, and the values obtained show how the gradient of stress generated by sudden cooling is localized principally in the surface portion of the specimen itself, given that the material is a poor conductor of heat.

[0023] From the above consideration, it follows that it is not necessary to reach a homogeneous temperature during cooling throughout the specimen to have cleavage: in fact, during cooling the maximum value of the tensile stresses is located on the surface, and the gradient goes to zero in the surface layer of the material, i.e., within 1-2 cm from the surface.

[0024] Figure 3 represents the profile of the stresses σ_y within the core of the specimen in the direction X. The profile was calculated for an initial temperature of treatment of 500°C, which experimentally proved unsuitable: the specimen in fact shattered and was not cleaved. The profile of the stresses σ_y confirms the experimental data: the values of tensile stress on the surfaces of the specimen are very close to the fracture strength of porphyry. Furthermore, it appears from Figure 3 that the stress profile at a depth of 1 cm from the surface goes to zero, showing that also the thermal gradient becomes negligible at the same distance.

[0025] Figure 4 gives the stress profiles as in Figure 3 but calculated for different temperatures of treatment. From this graph it emerges that, for a temperature of 450°C, a stress of approximately 19 MPa is reached on the surface, a value which falls within the confidence interval of the fracture strength of porphyry.

[0026] Figure 5 gives the values of the maximum surface stress (σ_y) as a function of the initial temperature of treatment. This graph enables calculation of the temperature of start of treatment as a function of the state of stress that it is intended to obtain. It may be inferred from the graph that the temperature of 450°C is likely to be the maximum limit of temperature to which porphyry can be heated; presumably, once this temperature is exceeded thermal shock occurs in the cooling step.

Procedures and materials used

[0027] The method according to the present invention used for the cleavage of a specimen of stone material in the form of a slab consists in heating the specimen in the furnace, taking it out when hot and immersing it in a fluid or liquid at relatively low temperature, with the aim of generating a state of tensile stress within the specimen so that the cleavage is obtained along the planes of discontinuity.

[0028] To verify the goodness of the procedure defined, a number of tests were conducted using specimens of porphyry with dimensions of 12 cm x 13 cm x 18 cm. The specimens contained planes of discontinuity orthogonal to the directions of shear.

[0029] For heating the specimens an electric furnace having a power of 4.2 kW was used, with the capacity of reaching the maximum temperature of 1200°C and with a chamber of dimensions 21 cm x 15 cm x 30 cm.

[0030] For cooling a bath was used containing a volume of water equal to 50 cm x 35 cm x 20 cm. The initial temperature of the cooling water was approximately 20-25°C.

Experimental results

a) Test at 500°C

[0031] A specimen was put into the furnace at 25°C, the temperature was raised to 500°C, and the specimen was left inside the furnace for approximately 8 hours. Finally, it was taken out using steel pliers and immersed immediately in water at a temperature of approximately 20-25°C.

[0032] The specimen was cleaved not only along the planes of discontinuity but also along planes having orthogonal lies, an event that indicates that thermal shock has occurred and not cleavage along the slip planes. This behaviour is in accordance with what was previously envisaged for the application of temperatures higher than 477°C.

b) Test at 400°C

[0033] In this case, the procedure described above was followed, with the temperature of the furnace, however, set at 400°C.

[0034] The presence of two planes of cleavage corresponding to the slip planes present emerged.

[0035] Subsequently, other tests were conducted with a new series of specimens in which five planes of discontinuity were present.

Specimen 1

[0036] Insertion into the furnace at a temperature of 25°C

[0037] Final temperature of the furnace: 400°C

[0038] Stay time in the furnace: 2 hours

[0039] The time of heating of the specimen in the furnace was set at two hours, without achieving a homogeneity of temperature within the specimen prior to cooling in water.

[0040] The specimen was cleaved - as expected - along the lies of the planes of discontinuity in a regular way without there having occurred thermal shock in any point of the specimen. This fact was confirmed by the observation of the surface morphology: no sign of thermal shock was noted, but only a sharp and clean cleavage along a plane of discontinuity.

Specimen 2

[0041] Insertion into the furnace at a temperature of 25°C

[0042] Final temperature of the furnace: 450°C

[0043] Stay time in the furnace: 7 hours

[0044] The second specimen was subjected to more drastic conditions of treatment: a sharp cooling starting from a temperature of 450°C.

[0045] Cleavage occurred along the lies of the five planes of discontinuity, as in the reference specimen treated manually. Unfortunately, the treatment was too drastic, thus leading to fractures due to thermal shock outside the planes of discontinuity. This event was consequent upon the attainment of values of the stresses within the specimen comparable to the fracture strength of isotropic porphyry (i.e., considered without slip planes).

Specimen 3

[0046] Insertion into the furnace at a temperature of 25°C

[0047] Final temperature of the furnace: 300°C

[0048] Stay time in the furnace: 8 hours

[0049] This test showed that also a temperature of 300°C with a time sufficient for achieving thermal homogeneity of the specimen - in this case equal to 8 hours - is sufficient to obtain a cleavage along the planes of discontinuity present in the specimen. Six pieces were obtained as in the reference specimen.

[0050] It was found that a weaker plane of discontinuity had split in the furnace during the heating step; the heating step can in fact generate stresses, albeit of a smaller amount than those generated during the cooling step.

Specimen 4

[0051] Insertion into the furnace at a temperature of 25°C

[0052] Final temperature of the furnace: 250°C

[0053] Stay time in the furnace: 8 hours

[0054] The temperature of heating, 250°C, proved sufficient to bring about cleavage of porphyry along a surface plane of discontinuity, but not such as to enable propagation of the cleavage throughout the slip plane.

[0055] The stresses generated by a thermal jump of this amount seem to be sufficient to cleave the stone material only along the "weaker" planes of discontinuity.

Specimen 5

[0056] Insertion into the furnace at a temperature of 25°C

[0057] Final temperature of the furnace: 300°C

[0058] Stay time in the furnace: 1 hour

[0059] The result obtained was favourable: notwithstanding the brevity of the stay time of the specimen in the furnace, cleavages were obtained on four planes of discontinuity as.expected. This result shows that the thermal gradients during cooling are prevalently superficial and that, consequently, also the stress profiles seem to be localized prevalently in the surface layer and presumably within the first centimetre of depth.

[0060] It consequently appears sufficient to raise the temperature only of a surface layer of the specimen to obtain its cleavage along the planes of discontinuity.

Processing of the data collected

Calculation of the fracture strength of the planes of discontinuity

[0061] Represented in Figure 6 is the graph of the stress S_Y in the core of the specimen in the direction x (Figure 2). The profile of the stress in Figure 6 was calculated for a specimen of porphyry simply heated homogeneously to a temperature of 250°C. This temperature was chosen because, on the basis of the tests conducted, it is deemed that this temperature is likely to correspond to a lowest-limit temperature to obtain cleavage along the lies of the planes of discontinuity of a block of porphyry. In particular, reference was made to the procedure of cleavage of Specimen 4. Specimen 4 had two planes of discontinuity both at a distance of 3 cm from the planes XZ. Whereas one of the two planes of discontinuity split completely, the other was only marked on the surface where the advance of the cleavage stopped. It is consequently reasonable to believe that the stress generated by heating the specimen to a temperature of 250°C and reaching said temperature only in a surface layer at a depth of approximately 3 cm of the specimen is sufficient to reach the fracture strength of the slip planes. From Figure 6 it emerges that at a distance of 3 cm from the surface XZ the tensile stress is equal to approximately 10 MPa. On the basis of this datum and knowing that the fracture strength of porphyry is equal to or higher than 19 MPa, it may be presumed that, in order to cleave porphyry along the planes of discontinuity without causing thermal shock in the material, it is useful to generate in the material values of tensile stress of between 10 MPa and 19 MPa.

Analysis of sensitivity

[0062] Thanks to the values calculated it is now possible to carry out an analysis of sensitivity along the axes X, Y, Z with the purpose of evaluating the variations of the maximum stress as a function of the dimensions and geometry of the specimen.

[0063] For a more effective analysis, the temperature of treatment was arbitrarily set at 430°C, since this temperature is sufficiently high to obtain high values of stress but also sufficiently low to prevent thermal shock.

[0064] Represented in Figure 7 is the effect of the geometry of the specimen on the generation of the stresses. To study the geometrical effect, the parameter t, i.e., the thickness, was made to vary keeping fixed the parameter c/b (see Figure 2 for the definition of the parameters t, b and c). The latter ratio is an indicator of shape of the specimen. For c/b = 1 the specimen is a parallelepiped with a square base whilst by increasing the ratio c/b the basic figure is increasingly lengthened.

[0065] From an analysis of the graph of the stress σ_y, given in Figure 7, it emerges that a specimen with a high c/b is in a more drastic condition, i.e., that it has a stress profile higher than a specimen with a square base. Furthermore, it was found that for b greater than approximately 12 cm, the maximum stress σ_y that is generated becomes constant.

[0066] This phenomenon occurs because, by increasing the areas of thermal exchange, also the thermal exchange itself increases: this effect is found as long as the areas do not become so large that the thermal exchange is only limited by the coefficient of thermal diffusion of the material.

[0067] Represented in Figure 8 is the effect of the dimensions of the specimen on the generation of the stresses. The geometry of the specimen was arbitrarily fixed with a square base. The thickness t was made to vary, taking into consideration different dimensions of the base. From an analysis of the graphs reproduced in Figure 8 it is found that, if the thickness t is equal to or greater than that of the base sides b and c, the stress along Y is maximum since the thermal exchange occurs prevalently along faces XY and ZY rather than ZX. For smaller values of t, the stress S_Y assumes a lower value. With reference to a practical example, a square slab of side b = 1 m is taken: it will break on the slip planes only for thicknesses greater than approximately 35 cm, given that, for t = 350 mm, $S_Y > 10$ MPa.

[0068] Further background to the invention is given by:

1. Paolo Tomio, Fiorino Filippi, "Il manuale del porfido", E.S.PO.
2. Bruno A. Boley, Jerome H. Weiner, "Theory of thermal stress", Dover Publications Inc.
3. Frank P. Incropera, David P. De Witt, "Fundamentals of heat and mass transfer", J. Wiley & Sons.

Claims

1. A method for the cleavage of a block of stone material in the form of slabs, wherein said cleavage occurs along planes of discontinuity, known as slip planes, of said block, said method comprising the following steps:

i) heating of said block; and
ii) rapidly cooling of said block,

wherein said cooling step generates stresses in said block leading to said cleavage and wherein said heating step envisages heating the centre of said block at a central heating temperature lower than the temperature T_c of thermal shock of said block and wherein said cooling step envisages cooling the surface of said block at a temperature T_s lower than said central heating temperature, wherein said temperature of thermal shock T_c and said temperature T_s at the surface are related by the equation:

$$\sigma_{st} = \frac{E\alpha}{1-\nu}(T_c - T_s) \qquad (0.2)$$

where σ_{st} is the strength of the stone material constituting said block, α the coefficient of thermal expansion of the stone material constituting said block, and finally E and ν the elastic modulus and Poisson's ratio, respectively, of the stone material constituting said block.

2. The method according to Claim 1, **characterized in that** said heating step has a duration of between 10 minutes and 8 hours.

3. The method according to Claim 2, **characterized in that** said heating step has a duration of between 10 minutes and 4 hours.

4. The method according to Claim 3, **characterized in that** said heating step has a duration of between 10 minutes and 2 hours.

5. The method according to Claim 1, **characterized in that** said heating step envisages heating said block at a temperature of between 100 and 600°C.

6. The method according to Claim 5, **characterized in that** said heating step envisages heating said block at a temperature of between 100 and 500°C.

7. The method according to Claim 6, **characterized in that** said heating step envisages heating said block at a temperature of between 300 and 400°C.

8. The method according to Claim 1, **characterized in that** said cooling step has a duration of approximately 10 seconds.

9. The method according to Claim 1, **characterized in that** said cooling step envisages cooling said block in a liquid, wherein said liquid has a temperature of between 15 and 50°C.

10. The method according to Claim 9, **characterized in that** said cooling step envisages cooling said block in a liquid, wherein said liquid has a temperature of between 15 and 30°C.

11. The method according to Claim 10, **characterized in that** said cooling step envisages cooling said block in a liquid, wherein said liquid has a temperature of between 20 and 25°C.

Patentansprüche

1. Verfahren zur Spaltung eines Blocks aus Steinmaterial in der Form von Platten, worin sich die Spaltung entlang Unstetigkeitsebenen, bekannt als Gleitebenen, des Blocks vollzieht, wobei das Verfahren die folgenden Schritte umfasst:

   i) Erwärmen des Blocks; und
   ii) rasches Abkühlen des Blocks,

   worin der Abkühlschritt Spannungen in dem Block erzeugt, die zu der Spaltung führen und worin der Erwärmungsschritt ein Erwärmen der Mitte des Blocks bei einer mittigen Erwärmungstemperatur vorsieht, die geringer ist als die thermische Schocktemperatur T_c des Blocks und worin der Abkühlschritt ein Abkühlen der Oberfläche des Blocks bei einer Temperatur T_s vorsieht, die geringer als die mittige Erwärmungstemperatur ist,
   worin die thermische Schocktemperatur T_c und die Temperatur T_s an der Oberfläche durch die Gleichung

$$\sigma_{sl} = \frac{E\alpha}{1-\nu}\left(T_c - T_s\right) \qquad (0.2)$$

zueinander in Beziehung stehen, wobei σ_{sl} die Festigkeit des den Block bildenden Steinmaterials ist, α der thermische Ausdehnungskoeffizient des den Block bildenden Steinmaterials ist und schließlich E und ν der Elastizitätsmodul bzw. die Poissonzahl des den Block bildenden Steinmaterials sind.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der Erwärmungsschritt eine Dauer zwischen 10 Minuten und 8 Stunden aufweist.

3. Verfahren nach Anspruch 2, **dadurch gekennzeichnet, dass** der Erwärmungsschritt eine Dauer zwischen 10 Minuten und 4 Stunden aufweist.

4. Verfahren nach Anspruch 3, **dadurch gekennzeichnet, dass** der Erwärmungsschritt eine Dauer zwischen 10 Minuten und 2 Stunden aufweist.

5. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der Erwärmungsschritt eine Erwärmung des Blocks bei einer Temperatur zwischen 100 und 600°C vorsieht.

6. Verfahren nach Anspruch 5, **dadurch gekennzeichnet, dass** der Erwärmungsschritt eine Erwärmung des Blocks bei einer Temperatur zwischen 100 und 500°C vorsieht.

7. Verfahren nach Anspruch 6, **dadurch gekennzeichnet, dass** der Erwärmungsschritt eine Erwärmung des Blocks bei einer Temperatur zwischen 300 und 400°C vorsieht.

8. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der Abkühlschritt eine Dauer von etwa 10 Sekunden aufweist.

9. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der Abkühlschritt ein Abkühlen des Blocks in einer Flüssigkeit vorsieht, worin die Flüssigkeit eine Temperatur zwischen 15 und 50°C aufweist.

10. Verfahren nach Anspruch 9, **dadurch gekennzeichnet, dass** der Abkühlschritt ein Abkühlen des Blocks in einer Flüssigkeit vorsieht, worin die Flüssigkeit eine Temperatur zwischen 15 und 30°C aufweist.

11. Verfahren nach Anspruch 10, **dadurch gekennzeichnet, dass** der Abkühlschritt ein Abkühlen des Blocks in einer Flüssigkeit vorsieht, worin die Flüssigkeit eine Temperatur zwischen 20 und 25°C aufweist.

Revendications

1. Un procédé pour le fendage d’un bloc de matériau pierreux en forme de dalles, dans lequel ledit fendage a lieu le long de plans de discontinuité, connus sous le nom de plans de glissement, dudit bloc, ledit procédé comprenant les étapes suivantes :

   (i) chauffage dudit bloc ; et
   (ii) refroidissement rapide dudit bloc,

   dans lequel ladite étape de refroidissement produit dans ledit bloc des contraintes conduisant audit fendage, et dans lequel ladite étape de chauffage prévoit le chauffage du centre dudit bloc à une température centrale de chauffage inférieure à la température T_c de choc thermique dudit bloc, et dans lequel ladite étape de refroidissement prévoit le refroidissement de la surface dudit bloc à une température T_s inférieure à ladite température centrale de chauffage, dans lequel ladite température de choc thermique T_c et ladite température en surface T_s sont liées par l’équation :

$$\sigma_{st} = \frac{E\alpha}{1-\nu}(T_c - T_s) \qquad (0.2)$$

où σ_{st} est la rigidité du matériau pierreux constituant ledit bloc, α le coefficient de dilatation thermique du matériau pierreux constituant ledit bloc, et enfin E et ν le module élastique et le coefficient de Poisson, respectivement, du matériau pierreux constituant ledit bloc.

2. Le procédé selon la revendication 1, **caractérisé en ce que** ladite étape de chauffage a une durée comprise entre 10 minutes et 8 heures.

3. Le procédé selon la revendication 2, **caractérisé en ce que** ladite étape de chauffage a une durée comprise entre 10 minutes et 4 heures.

4. Le procédé selon la revendication 3, **caractérisé en ce que** ladite étape de chauffage a une durée comprise entre 10 minutes et 2 heures.

5. Le procédé selon la revendication 1, **caractérisé en ce que** ladite étape de chauffage prévoit le chauffage dudit bloc à une température comprise entre 100 et 600 °C.

6. Le procédé selon la revendication 5, **caractérisé en ce que** ladite étape de chauffage prévoit le chauffage dudit bloc à une température comprise entre 100 et 500 °C.

7. Le procédé selon la revendication 6, **caractérisé en ce que** ladite étape de chauffage prévoit le chauffage dudit bloc à une température comprise entre 300 et 400 °C.

8. Le procédé selon la revendication 1, **caractérisé en ce que** ladite étape de refroidissement a une durée d'approximativement 10 secondes.

9. Le procédé selon la revendication 1, **caractérisé en ce que** ladite étape de refroidissement prévoit le refroidissement dudit bloc dans un liquide, dans lequel ledit liquide a une température comprise entre 15 et 50 °C.

10. Le procédé de la revendication 9, **caractérisé en ce que** ladite étape de refroidissement prévoit le refroidissement dudit bloc dans un liquide, dans lequel ledit liquide a une température comprise entre 15 et 30 °C.

11. Le procédé selon la revendication 10, **caractérisé en ce que** ladite étape de refroidissement prévoit le refroidissement dudit bloc dans un liquide, dans lequel ledit liquide a une température comprise entre 20 et 25 °C.

Figure 1

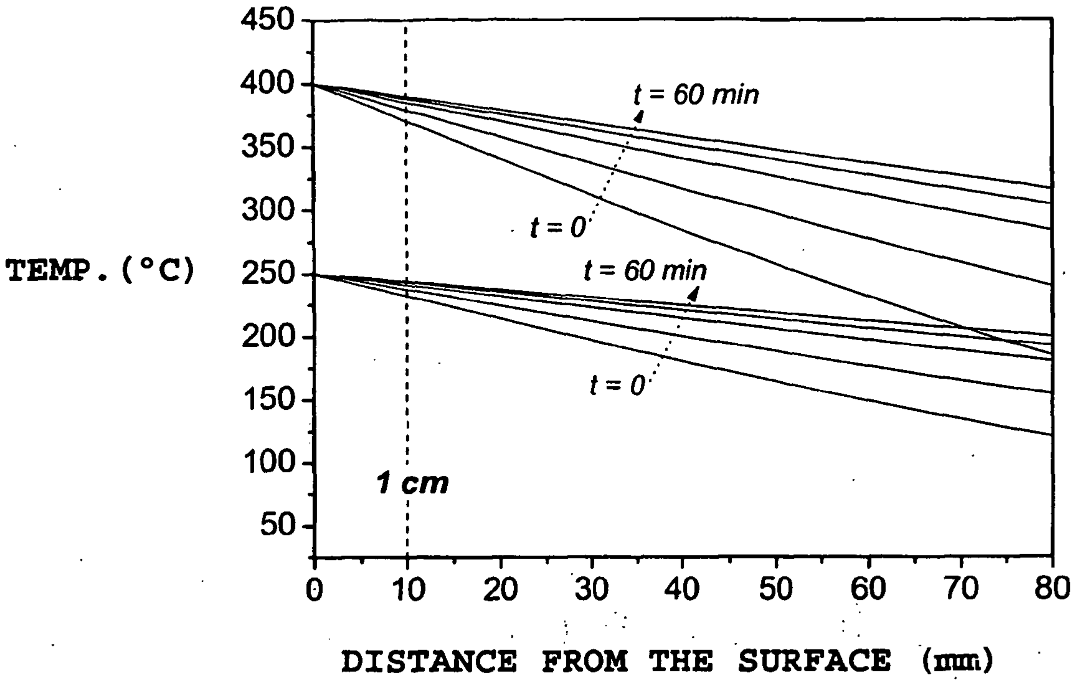


Figure 2

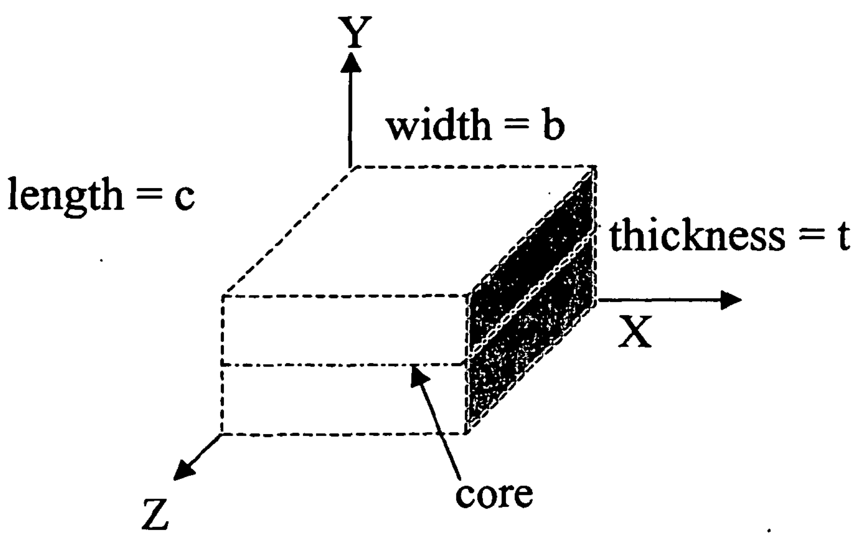


Figure 3

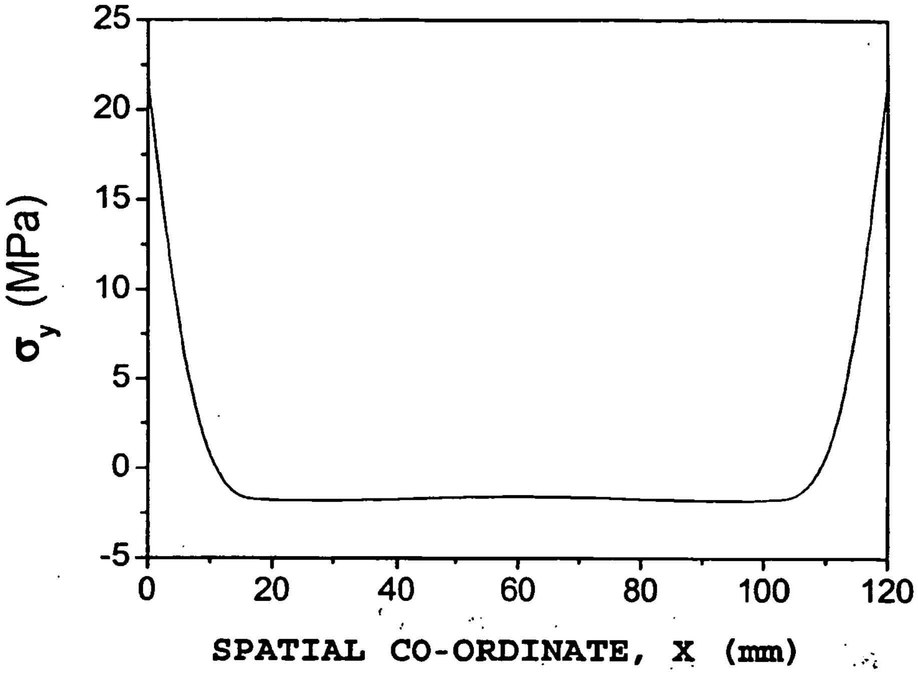


Figure 4

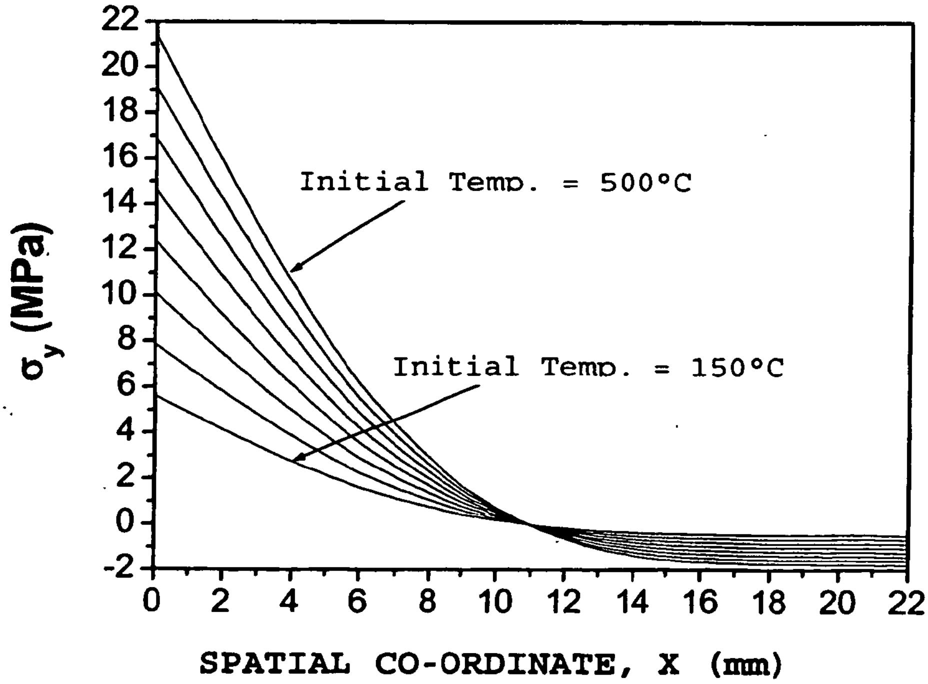
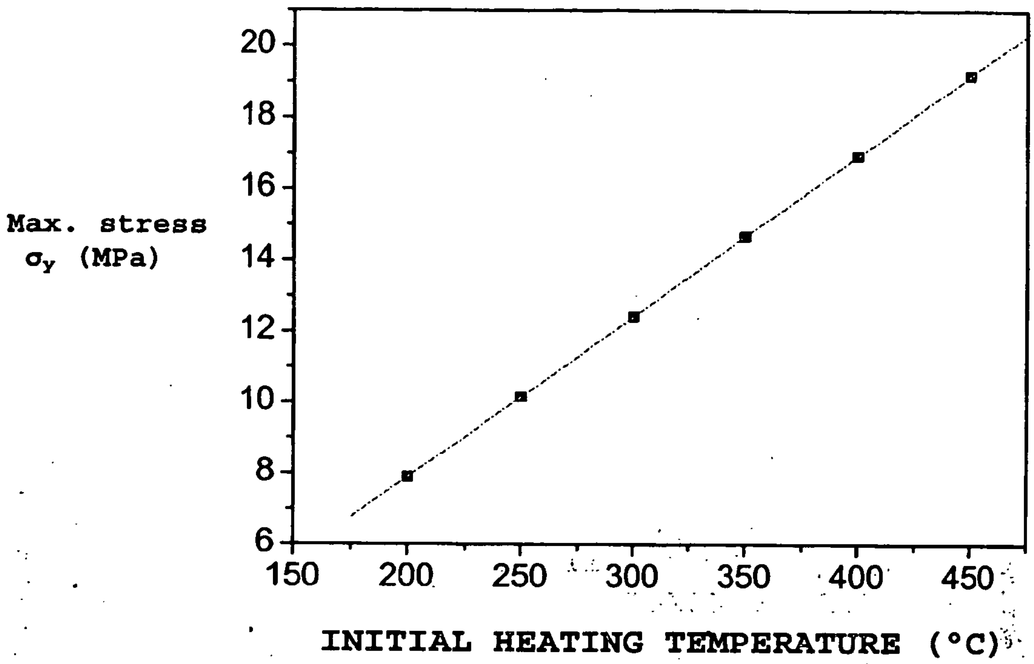


Figure 5



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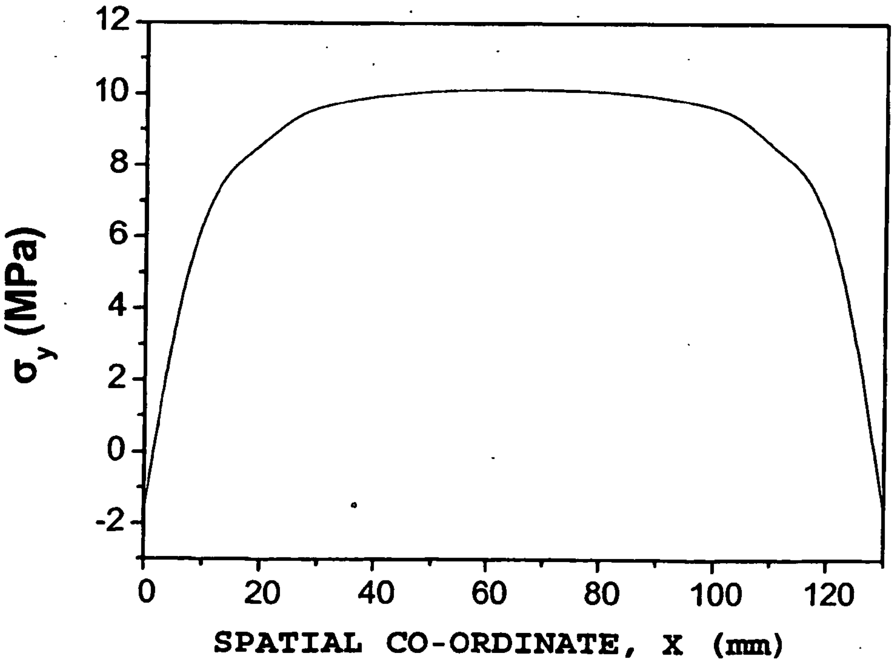


Figure 7

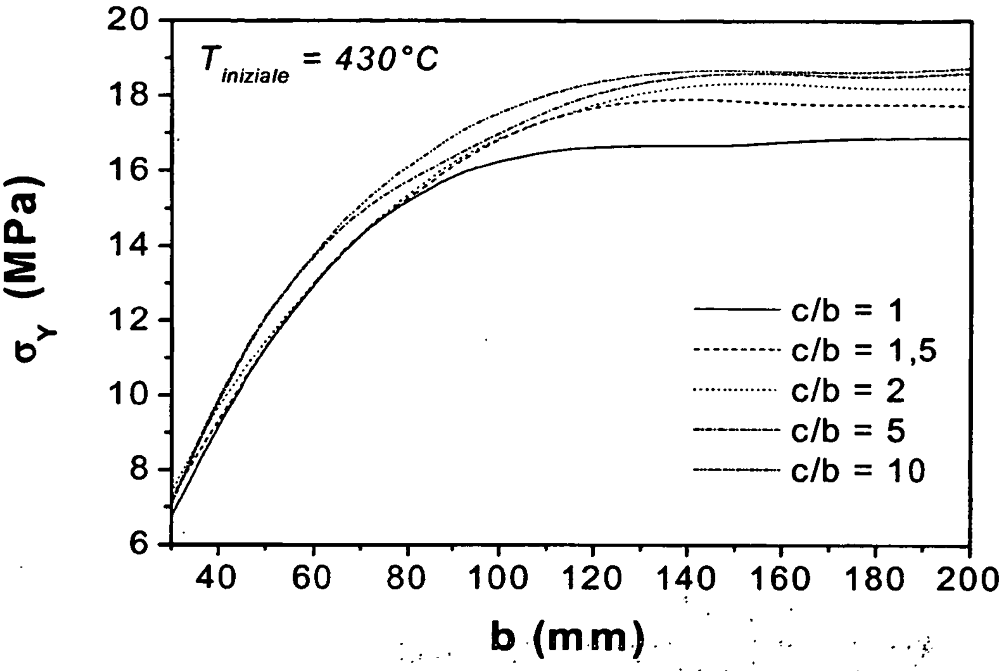
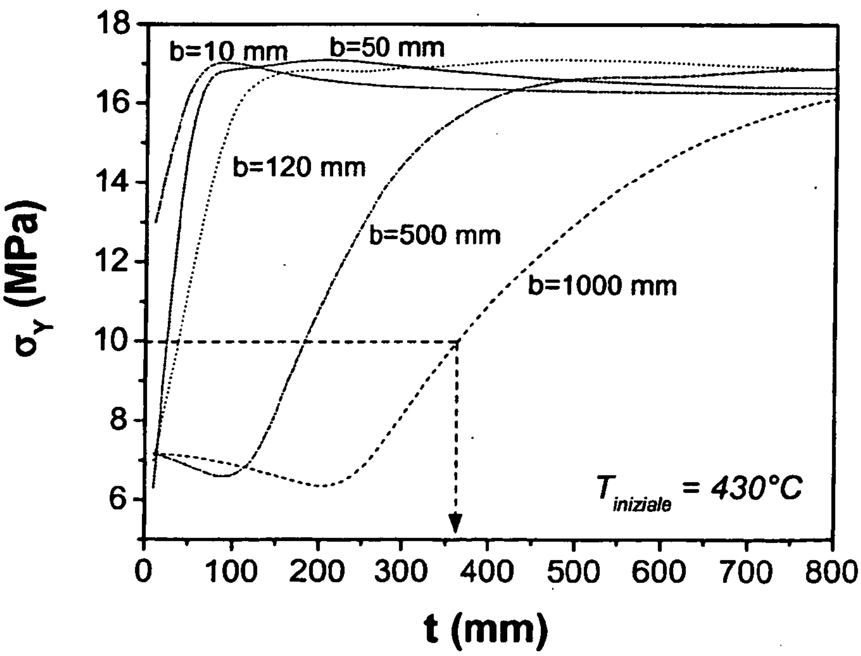


Figure 8



REFERENCES CITED IN THE DESCRIPTION

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