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(54) Titre : PROCESSUS DE FABRICATION D'UN ARTICLE MOULE LEGER ET ARTICLE MOULE FABRIQUE DE MOUSSE METALLIQUE
 (54) Title: PROCESS FOR PRODUCING A LIGHTWEIGHT MOLDED ARTICLE AND A MOLDED ARTICLE MADE OF METAL FOAM



Diagram A

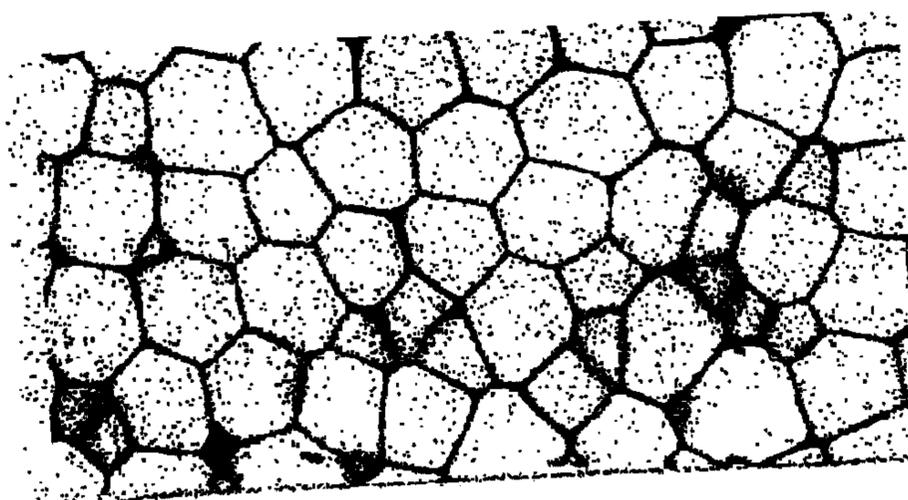


Diagram B

(57) **Abrégé/Abstract:**

A process for producing a lightweight molded part, comprising introducing a gas into a particle-containing molten metal to produce a metal foam having voids with a monomodal distribution of their dimensions, introducing the metal foam into a casting die, and compressing it therein essentially under all-round pressure; and the molded part made by this process.

Abstract

A process for producing a lightweight molded part, comprising introducing a gas into a particle-containing molten metal to produce a metal foam having voids with a monomodal distribution of their dimensions, introducing the metal foam into a casting die, and compressing it therein essentially under all-round pressure; and the molded part made by this process.

**Process For Producing A Lightweight Molded Article And
A Molded Article Made Of Metal Foam**

The invention relates to a process for producing a lightweight molded article, in which a metal foam is formed out of a particle-containing molten metal by introducing gas or gas mixtures into the melt, the melt is introduced at least partially into a casting die, and the liquid phase is allowed to solidify therein.

The invention further comprises a lightweight molded article made of metal foam, comprising a metal matrix in which particles are embedded and which encloses a plurality of essentially spherical and/or essentially ellipsoid voids.

Molded articles made of metal foam naturally have a low density and, due to their structure, have special mechanical material properties. For instance, such parts can be furnished with large deformations with degrees of compression up to 70% and more when two- or three-dimensional compressive stresses are applied. These materials with special properties can be advantageously used in technical applications, for example, as energy absorbers in automotive technology and the like.

When using such molded articles for selected functions with specific parameters, it is important to ensure identical and reproducible property characteristics of the materials.

A process for producing a particle-reinforced metal foam is known from EP 483 184 B. According to this document cell-forming gas is introduced into a metal melt having

composite material is formed, and the accumulated foam is removed from the surface of the melted material and allowed to solidify. However, this metal foam has bubbles with uncontrolled size or size distribution, which results in a highly uncertain property profile of the foam or molded article, as well as functional uncertainties.

According to EP 545 957 B1 and U.S. Pat. No. 5,221,234, another lightweight metal article has a plurality of closed and isolated, generally spherical pores with sizes in the range of 10 to 500 μm . Although such small pores with large differences in diameter can provide a metal part made with aluminum with a lower specific gravity in comparison with the bulk material, it usually is impossible to achieve a density of less than 1.0 g/cm^3 and a degree of compression more than 60% under defined conditions.

A number of sequentially operating (U.S. Pat. 5,281,251, DE 43 26 982 C1) and/or continuously operating (U.S. Pat. 5,334,236, EP 544 291 A1, DE 43 26 982 C1, WO 91/03578) processes and devices have been proposed for producing various shapes of lightweight parts made of metal foam, with which, in principle, articles which are quite operable can be produced. However, the mechanical properties thereof cannot be set with the precision which is often required.

The present invention provides a process of the type mentioned at the outset for producing a lightweight molded part with which the internal structure of the part can be made such that the material essentially has reasonably precise mechanical characteristics.

Furthermore, the present invention provides a molded part of the type mentioned above which exhibits a largely precise deformation behavior as a function of, in particular, the multi-dimensional compressive stress applied.

According to one aspect of the present invention there is provided a process for producing a lightweight molded article, comprising (a) introducing a gas into a particle-containing molten metal to produce a free-flowing metal foam having voids therein, the voids having a monomodal distribution of their dimensions and a proportionate maximum longitudinal extension of the voids in a range of 1 to 30 mm, (b) at least partially introducing the metal foam into a casting die and compressing it therein under substantially all-round pressure, and (c) allowing the molten phase to solidify.

According to another aspect of the present invention there is provided a lightweight molded article made of metal foam comprising a metal matrix with particles embedded therein and which encloses voids, the voids having a monomodal distribution of the dimensions thereof and a proportionate maximum longitudinal extension of the voids which ranges from 1 to 30 mm.

According to a further aspect of the present invention there is provided a free-flowing metal foam with a monomodal distribution of the dimensions of the voids and a proportionate maximum longitudinal extension thereof in the range of about 1 to about 30 mm is produced, introduced into a mold or casting die, and compressed therein essentially under all-round pressure (i.e., pressure from all sides, whereby the particle-containing molten metal boundary walls enclosing the voids are at least partially provided with flat-surfaced (planar) areas and the heat of solidification of the melt is dissipated.

3a

The advantages achieved with the invention can be seen essentially in that a monomodal distribution of the dimension of the voids in the metal foam provides a prerequisite for a predetermined material behavior under certain stress conditions. In this context, the proportionate maximum diameter of the voids is important for the level of the elastic limit of the material and the tolerable specific surface load during the subjecting of the part to compressive force.

In order to at least partially create planar areas in the boundary walls, it is necessary to subject the free-flowing foam to an essentially all-round, optionally low compressive pressure, which can result in several advantages. However, an advantage of particular importance is that in this manner the boundary walls and their nodal

areas in the foam material are favorably set or formed for a mechanical supporting or buckling load. This makes it possible, when exceeding a defined stress limit, to ensure that at high degrees of deformation or compression, a buckling of the foam walls or a collapse of the pores and an energy absorption takes place with low compaction of the lightweight part.

It has proved to be particularly advantageous, both for a monomodal distribution of the dimensions of the voids which can be produced within narrow limits and for a precise adjustment of the proportionate maximum diameter of the voids in the foam material, if the gas is introduced through at least one feed pipe with a small frontal area projecting inwardly into the melt, to develop the monomodal distribution of the dimensions of the voids.

For production-related and product quality reasons, it can be advantageous if the compression of the free-flowing metal foam is conducted in a casting die with interior dimensions which correspond to the desired dimensions of the molded part.

According to a particularly advantageous embodiment of the invention, particularly with regard to a desired material behavior during mechanical load, in a three-dimensional view the metal foam of the molded part shows a monomodal distribution of the maximum longitudinal extensions of the voids in the range of between about 1 and about 30 mm.

The advantages of a lightweight molded part made in this way from metal foam are essentially due to the fact that as already indicated above, favorable conditions regarding the

nodal development of the walls of the gas bubbles are achieved by means of a monomodality. With a bimodal, poly- or multi-modal distribution of the void size, thickened sections with possibly small and/or very small pores and cavity collapses are mostly present in the wall nodes, which on the one hand increases the specific gravity of the foam part and increases the metal resources for forming the same, and on the other hand can disturb the distribution of the force components, as a result of which a buckling of the wall area under load cannot be definitely determined.

The invention's advantages of the impact of the working mechanisms in the component distribution of the compressive forces can be reinforced, if the boundary walls enclosing the voids have planar areas at least in part.

If, as can advantageously also be provided, in a three-dimensional view of the metal foam, the ratio of the maximum longitudinal extensions of two different voids on an average of least 20 pairs, is less than about 45, then narrow compressive ranges within which a collapse of the foam voids begins can largely be achieved.

The precision of the transition from an elastic deformation to a plastic deformation of the material as a function of the compressive force can be further increased if, in a three-dimensional view of the metal foam, the ratio of the maximum longitudinal extensions of two different voids, over at least 20 pairs on an average, is less than about 30, preferably less than about 15, and in particular less than about 5. These values refer to voids produced, disregarding solidification cavities in the molded part.

The composition and the structure of the liquid metal and those of the boundary walls of the voids also are important for a metal foam production and for the behavior of the molded part during mechanical stress.

If reinforcing particles are embedded in the metal matrix in an evenly distributed fashion, a high and isotropic reinforcement of the base metal can be obtained with regard to the mechanical stress. In this context, it is also favorable if adjacent voids are completely separated from one another by the metal matrix. Individual cracks which can occur due to mechanical stress during cooling, are not effective under compressive pressures.

Particularly lightweight molded parts can be produced according to the invention if the metal matrix comprises a light metal, preferably aluminum or an aluminum alloy.

If, moreover, the particles embedded in the metal matrix are of a size of about 1 to about 50 μm , preferably about 3 to about 20 μm , a particularly advantageous weight/property ratio can be achieved.

Inclusions of nonmetallic particles, preferably SiC particles and/or Al_2O_3 particles and/or such of intermetallic phases, have proved to be particularly favorable for reinforcing or strengthening the base metal for a foaming and consolidation of the same, and/or for developing bubble partition walls which are strengthened against buckling.

In this context it is particularly advantageous if the volume fraction of the particles embedded in the metal

matrix is between about 10 vol % and about 50 vol %, preferably between about 15 vol % and about 30 vol %.

The favorable weight/property ratio of a lightweight molded part according to the present invention can be further improved if the density of the metal foam is less than about 1.05 g/cm^3 , preferably less than about 0.7 g/cm^3 , in particular less than about 0.3 g/cm^3 .

The present invention is further described in the detailed description which follows, with reference to the accompanying drawings and views of exemplary embodiments, wherein:

Fig. 1 shows sectional views of lightweight molded articles according to the invention;

Fig. 2 is a graphic representation of the relationship between density and compression stress of molded parts;

Fig. 3 is a graphic representation of the degree of compression as a function of the compression stress of molded parts;

Fig. 4 shows sectional views A, B, C of nodal forms in the foam walls;

Fig. 5 shows plan views A, B, C of foam parts with different volumetric density; and

Fig. 6 is a graphic representation of the average local density of a foam part according to the invention, and of a comparison foam.

In Fig. 1, view A and view B each show a void formation in an Al foamed part according to the invention on the basis of a sectional view. With a monomodal distribution of the dimensions, the largest longitudinal extensions of voids were determined to be in the range of between 20 and 12 mm,

with the proportionate maximum longitudinal extension being 17.2 mm. Although a compression of the free-flowing metal foam of only approx. 3.2% was conducted, planar areas are clearly formed in the boundary walls enclosing the voids.

The dependence of the compressive stress of a molded part on the density of the same can be seen from Fig. 2. It was established during developmental work that a monomodal distribution of the largest longitudinal extensions of the voids and an increasing uniformity of the same has a narrowing effect on the scattering range of the dependence. In other words: if there is a monomodal distribution of the voids in the foam part, and if the voids are of a specific size within narrow limits, then the start of the deformation or collapse during exposure of the same to a compressive force is a precise characteristic of the material. The behavior of a foam component can thus be precisely calculated, or the formation and the structure of the foam part can advantageously be adjusted for certain functions.

The stress as a function of the stress deformation is shown in a comparative way in Fig. 3 by means of the test results of three molded parts. The structure of lightweight molded parts 1 and 2 having a volumetric weight of 0.091 g/cm^3 and 0.114 g/cm^3 was according to the invention, whereas comparison part 3 showed a bimodal distribution of the dimension of the voids with material concentrations in the nodes of the foam walls. From the compression curves of parts 1 and 2 an extremely low compaction of the same can be seen up to a degree of compression of about 70%. Comparison part 3 shows a distinct compaction of the material up to a degree of compression of about 45%, which

continues to increase even further from this value. This suggests an effect of the bimodal distribution of the void dimensions.

Fig. 4 shows nodal forms in the foam wall of lightweight parts on the basis of sectional views.

View A shows a sharp-edged nodal formation of the wall between three cavities. Such nodes have a tendency to crack and break prematurely in the connecting area.

A thickened wall node can be seen in view B. This nodal formation leads to an increased specific gravity and an unfavorable distribution of force components when the part is subjected to compression.

View C shows a node with wall parts wherein both the thickness of the walls and the nodal mass are favorably formed with regard to a high compression deformation with low compaction of the part at high degrees of compression.

Fig. 5 shows metal foam parts without thickening formed according to the invention, wherein the gas was introduced through feed pipes projecting inwardly into the melt with different release parameters for the bubbles. A monomodal distribution of the respective dimensions of the gas bubbles can be seen. The part according to View A has a specific gravity of 0.1 g/cm^3 , those according to View B and View C have specific gravities of 0.2 g/cm^3 and 0.4 g/cm^3 , respectively.

Computer tomography data can be used to calculate values of the local densities (density mapping). An averaging

process for calculating the local densities makes it possible to determine the material distribution between the averaging volumes. Diagrams of the calculated density values of tests can provide information on the homogeneity of a lightweight molded article.

Fig. 6 shows the relative frequency of the mean local density in a molded part according to the invention (labeled 1) and in a comparison part (2), calculated according to a computer tomography process. At 0.22 g/cm^3 the mean local density of part 1 has a narrow frequency maximum, which indicates a monomodal distribution of the dimension of the voids and a narrow range of the proportionate maximum longitudinal extensions thereof. In contrast, the multimodal comparison part is characterized by a broad progression of the mean local density values, showing a clear drop.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A process for producing a lightweight molded article, the process comprising the steps of:

(a) introducing a gas into a particle-containing molten metal through at least one feed pipe which projects inwardly into the molten metal for producing therein a free-flowing metal foam having voids enclosed by boundary walls, the voids having averaged maximum longitudinal dimensions corresponding to a monomodal distribution ranging from 1 to 30 mm;

(b) at least partially introducing the metal foam into a casting die and compressing therein the metal foam under substantially all-round pressure providing the boundary walls of the voids with at least partially planar areas; and

(c) allowing the molten phase to solidify.

2. The process of claim 1, wherein the gas comprises a mixture of at least two gases.

3. The process of claim 1 or 2, wherein the casting die has interior dimensions corresponding to desired dimensions of the molded article.

4. The process of any one of claims 1 to 3, wherein the ratio of the maximum longitudinal dimensions of a pair of voids, expressed as mean of at least 20 pairs, is lower than 45.

5. The process of claim 4, wherein said ratio is lower than 15.

6. The process of any one of claims 1 to 5, wherein the lightweight molded article comprises a light metal.
7. The process of any one of claims 1 to 6, wherein the light metal comprises at least one of aluminum and an aluminum alloy.
8. The process of any one of claims 1 to 7, wherein the particles comprise particles selected from the group consisting of SiC, Al₂O₃, intermetallic compounds and mixtures thereof.
9. The process of any one of claims 1 to 8, wherein particles of the molten metal have a diameter of 1 to 50 μm .
10. The process of claim 9, wherein the particles have a diameter of 3 to 20 μm .
11. The process of any one of claims 1 to 10, wherein a volume fraction of the particles in the molten metal is 10 vol % to 50 vol %.
12. The process of claim 11, wherein a volume fraction of the particles in the molten metal is 15 vol % to 30 vol %.
13. The process of any one of claims 1 to 12, wherein the metal foam has a density of less than 1.05 g/cm³.
14. The process of claim 13, wherein the metal foam has a density of less than 0.7 g/cm³.
15. A lightweight molded article made of metal foam comprising a metal matrix with particles embedded therein

and which encloses voids having averaged maximum longitudinal dimensions corresponding to a monomodal distribution ranging from 1 to 30 mm.

16. The lightweight molded article of claim 15, wherein the voids are substantially spherical or substantially ellipsoid in shape.

17. The lightweight molded article of claim 15 or 16, wherein boundary walls of the metal matrix which enclose the voids at least partially have planar areas.

18. The lightweight molded article of claim 15, 16 or 17, wherein the ratio of the averaged maximum longitudinal dimensions of a pair of voids, expressed as mean of at least 20 pairs, is lower than 45.

19. The lightweight molded article of claim 18, wherein said ratio is lower than 30.

20. The lightweight molded article of claim 19, wherein said ratio is lower than 15.

21. The lightweight molded article of claim 20, wherein said ratio is lower than 5.

22. The lightweight molded article of any one of claims 15 to 21, wherein adjacent voids are completely separated from each other by the metal matrix.

23. The lightweight molded article of any one of claims 15 to 22, wherein said particles are substantially evenly distributed in the metal matrix.

24. The lightweight molded article of any one of claims 15 to 23, wherein said particles have a diameter of 1 to 50 μm .

25. The lightweight molded article of claim 24, wherein said particles have a diameter of 3 to 20 μm .

26. The lightweight molded article of any one of claims 15 to 25, wherein a volume fraction of the particles in the metal matrix ranges from 10 vol % to 50 vol %.

27. The lightweight molded article of claim 26, wherein a volume fraction of the particles in the metal matrix ranges from 15 vol % to 30 vol %.

28. The lightweight molded article of any one of claims 15 to 27, wherein the particles comprise particles of SiC, Al_2O_3 , intermetallic phases and mixtures thereof.

29. The lightweight molded article of claim 28, wherein the particles comprise particles of Al_2O_3 .

30. The lightweight molded article of any one of claims 15 to 29, wherein the metal matrix comprises a light metal.

31. The lightweight molded article of claim 30, wherein the light metal comprises at least one of aluminum and aluminum alloy.

32. The lightweight molded article of claim 31, wherein the light metal comprises aluminum.

33. The lightweight molded article of any one of claims 15 to 32, wherein the metal foam has a density of less than 1.05 g/cm^3 .

34. The lightweight molded article of claim 33, wherein the metal foam has a density of less than 0.7 g/cm^3 .

35. The lightweight molded article of claim 34, wherein the metal foam has a density of less than 0.3 g/cm^3 .

Application number / numéro de demande: 2390 766

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Diagram A

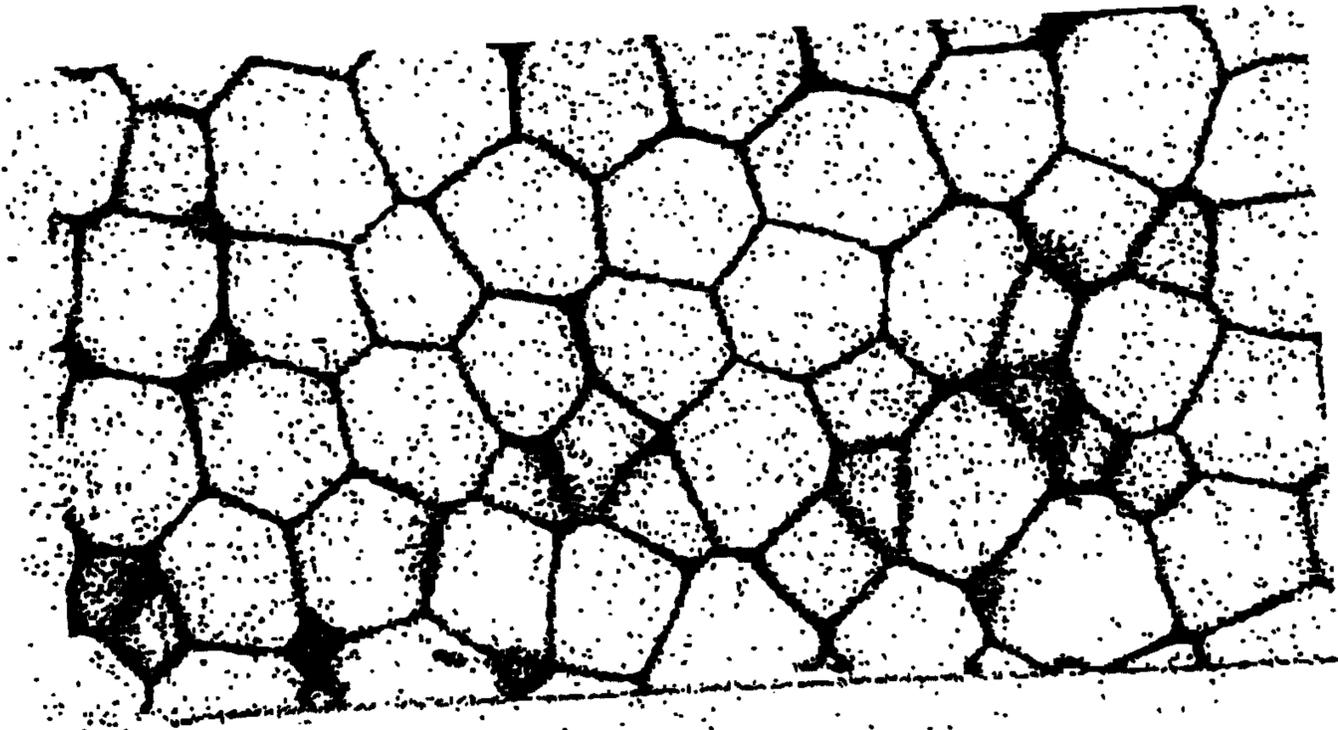


Diagram B

Fig. 1

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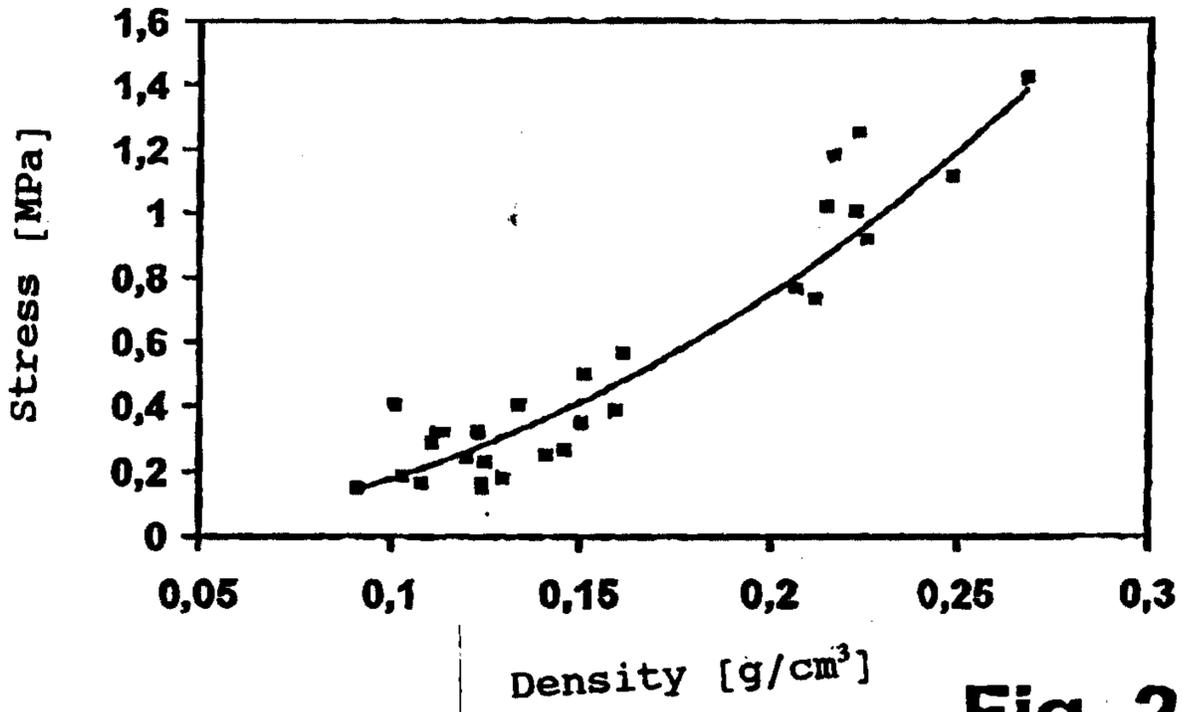


Fig. 2

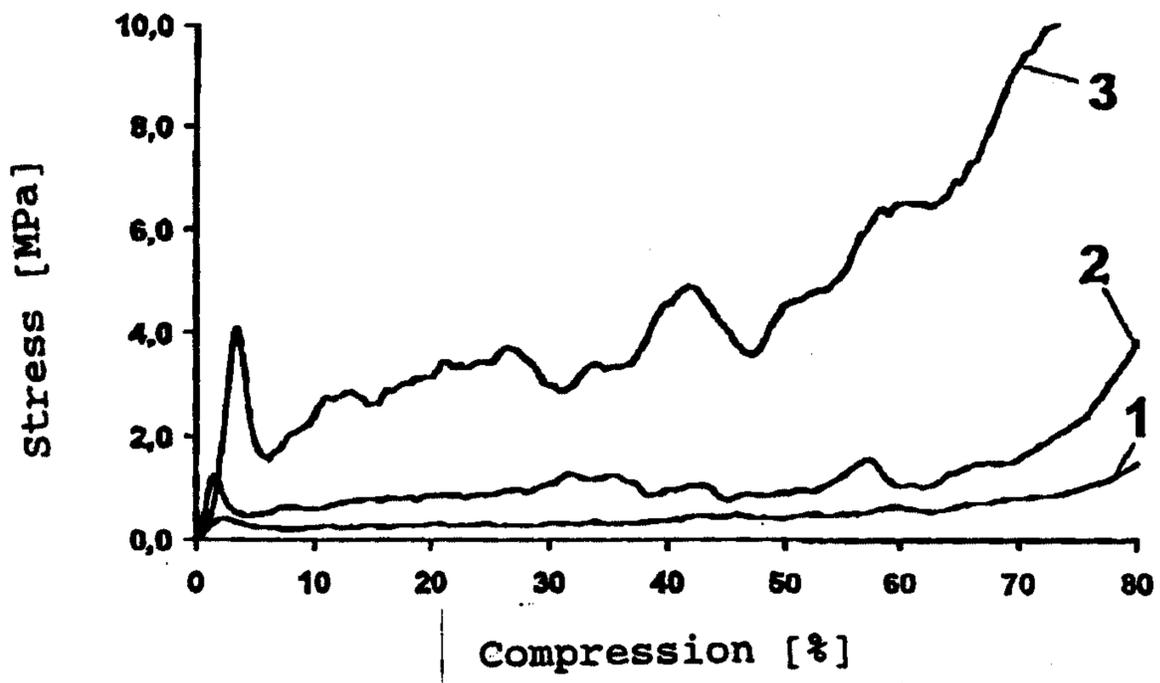


Fig. 3

Marks & Clerk

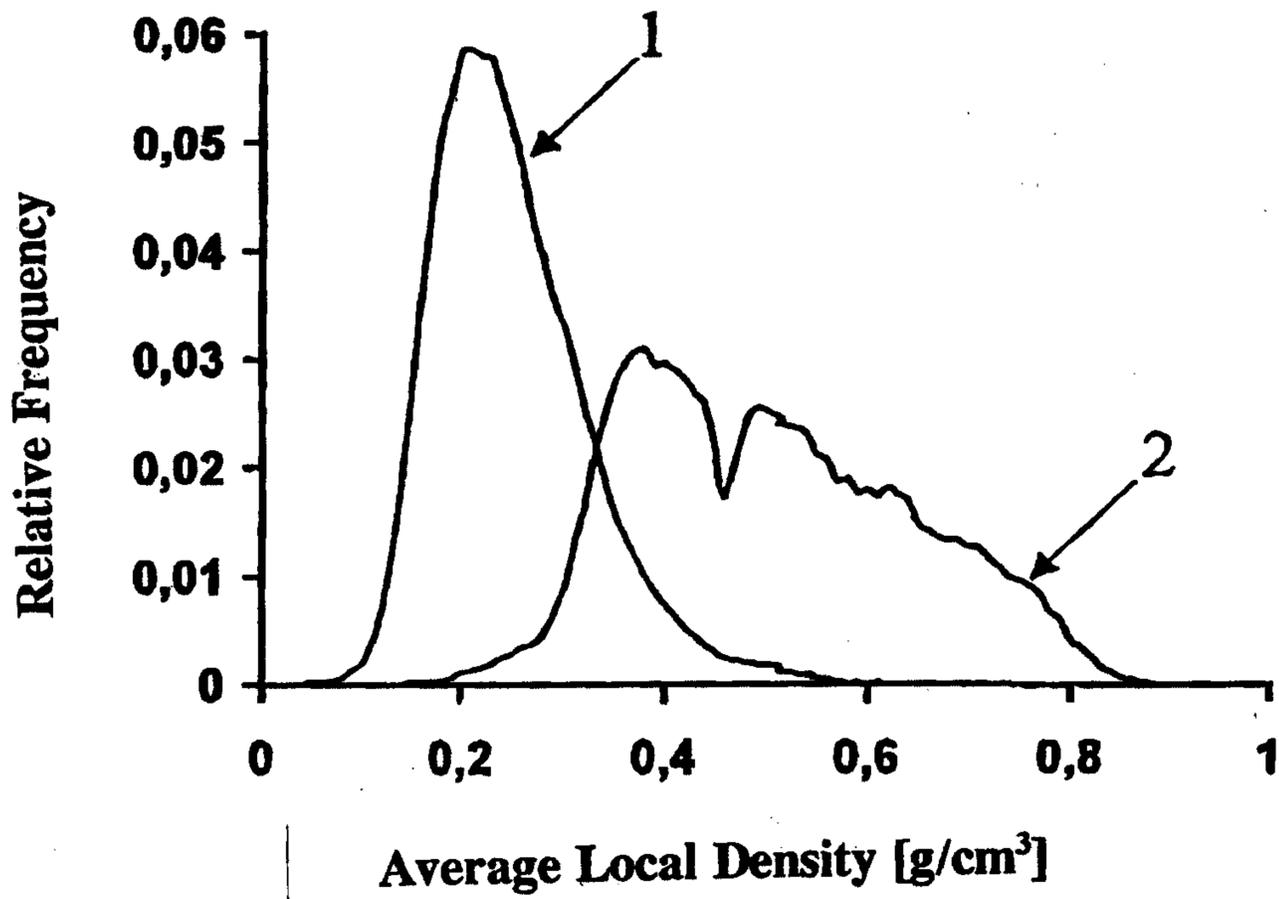


Fig. 6

Marks & Clerk



Diagram A

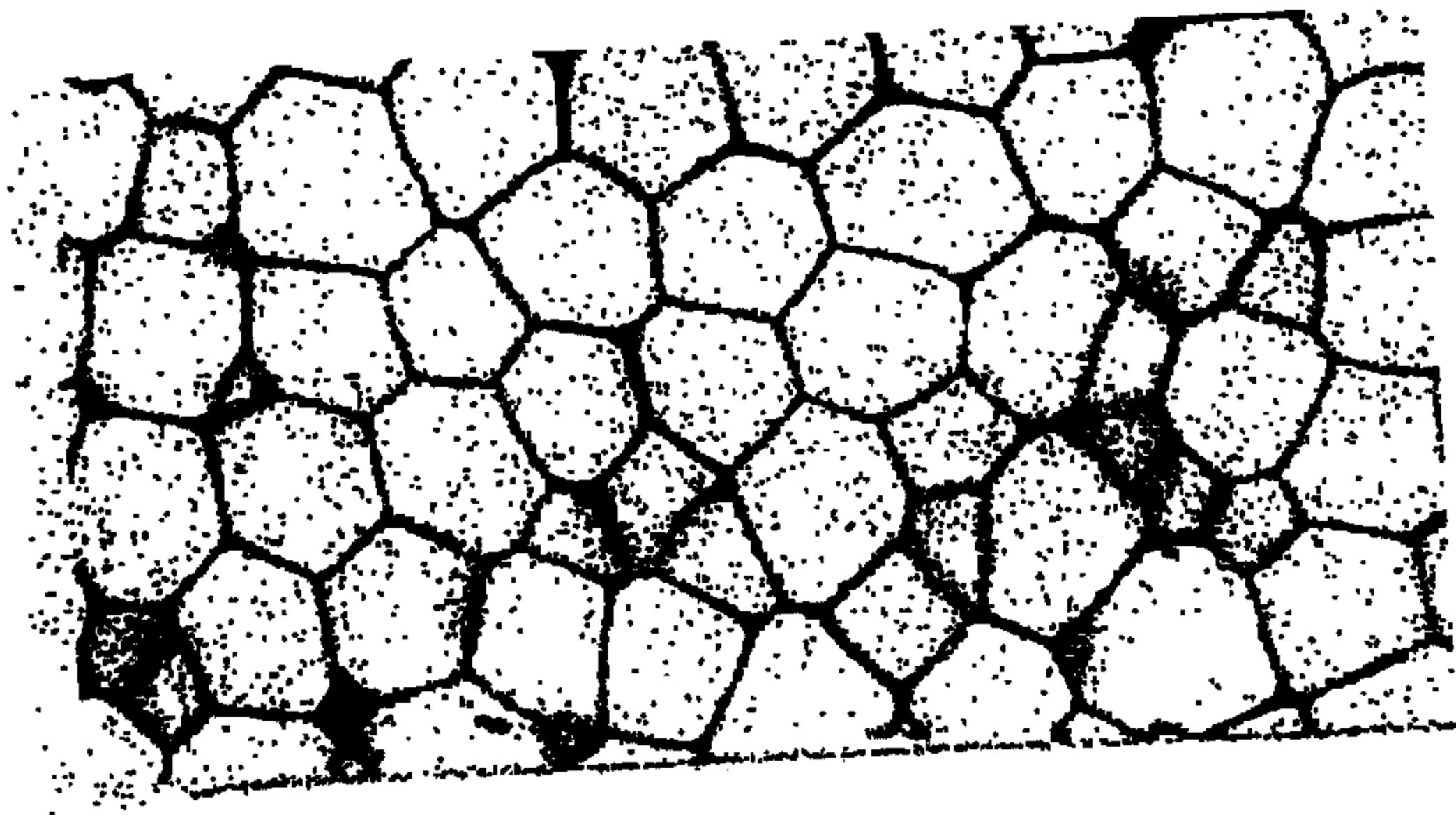


Diagram B