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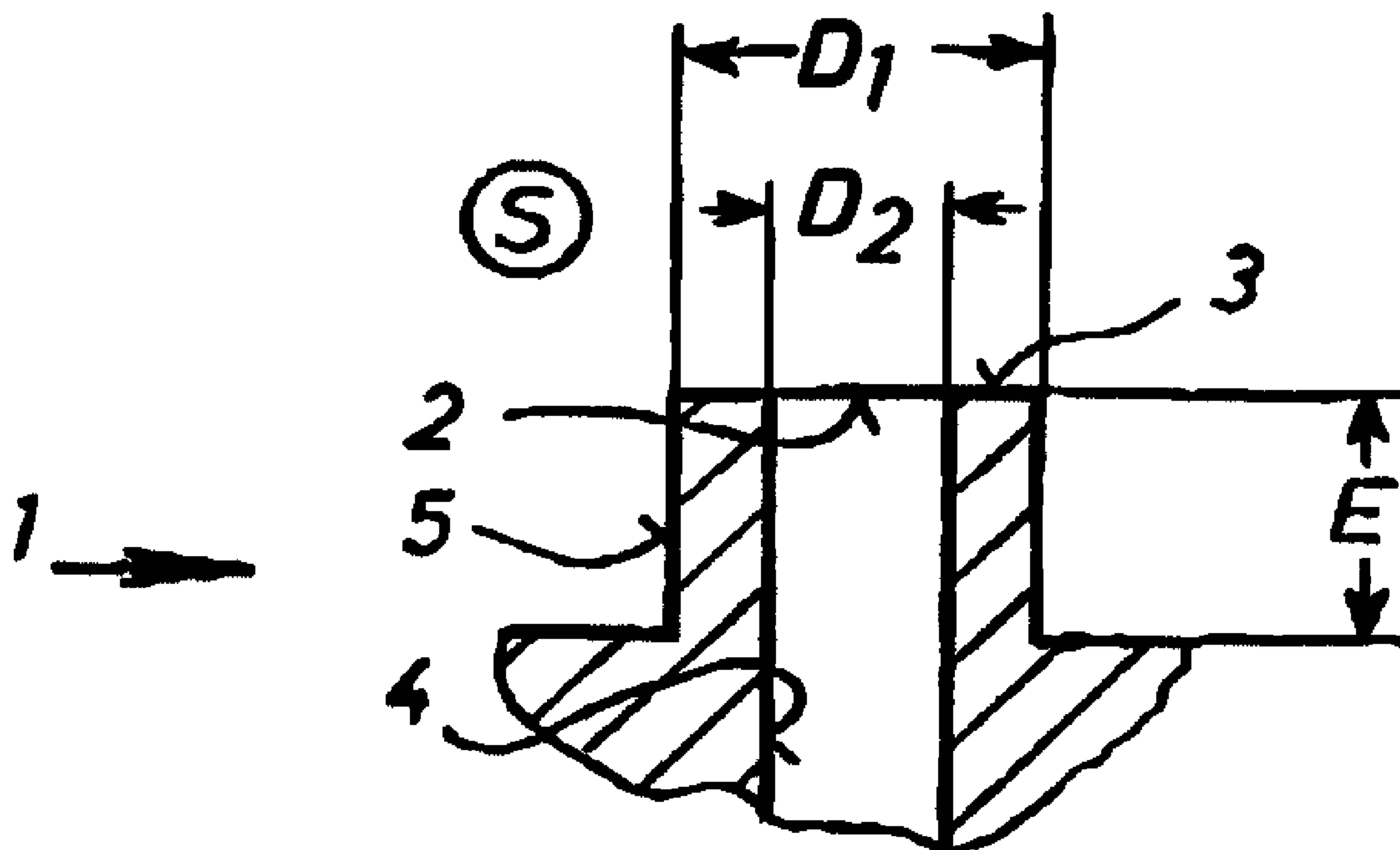
(72) Inventeurs/Inventors:  
DOBESBERGER, FRANZ, AT;  
FLANKL, HERBERT, AT;  
LEITLMEIER, DIETMAR, AT;  
BIRGMANN, ALOIS, AT

(73) Propriétaire/Owner:  
HUTTE KLEIN-REICHENBACH GESELLSCHAFT  
M.B.H., AT

(74) Agent: MARKS & CLERK

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(57) Abrégé/Abstract:

The invention relates to a device for introducing gas into a melt consisting of a foamable metal by means of at least one pipe for producing metal foam. Furthermore, the invention comprises a process for producing metal foam as well as a metal foam article. According to the invention, it is provided that at least one gas feed pipe (1) projects into the melt (S) so as to protrude and has a gas outlet cross section (2) with a surface of 0.006 to 0.2 mm<sup>2</sup> as well as a pipe face end (3) of less than 4.0 mm<sup>2</sup> at the projecting end and that there is uniformity of the diameter or the size of the respective individual bubbles and the size of the gas bubbles is controlled by a setting of the flow-in parameters of the gases. To ensure stable gas bubble separation criteria over long periods of time, the gas feed pipe consists of a ceramic, at least in the area of the projecting end.



### **Abstract**

The invention relates to a device for introducing gas into a melt consisting of a foamable metal by means of at least one pipe for producing metal foam.

Furthermore, the invention comprises a process for producing metal foam as well as a metal foam article.

According to the invention, it is provided that at least one gas feed pipe (1) projects into the melt (S) so as to protrude and has a gas outlet cross section (2) with a surface of 0.006 to 0.2 mm<sup>2</sup> as well as a pipe face end (3) of less than 4.0 mm<sup>2</sup> at the projecting end and that there is uniformity of the diameter or the size of the respective individual bubbles and the size of the gas bubbles is controlled by a setting of the flow-in parameters of the gases.

To ensure stable gas bubble separation criteria over long periods of time, the gas feed pipe consists of a ceramic, at least in the area of the projecting end.

Fig. 1

## **Device and Process for Producing Metal Foam**

The invention concerns a device for introducing gas into a molten mass of foamable metal by means of at least one pipe for producing metal foam.

Furthermore, the invention comprises a process for producing metal foam by injecting gas into a foamable molten metal.

Materials with new property profiles are increasingly required in innovative technology. A metal foam is a material of this type which, on the one hand, has a substantially lower, specific weight in comparison to a solid material and, on the other hand, has different mechanical properties and a completely different material performance.

Various processes are known for producing metal foam materials. For example, substances can be added to molten metal and distributed in it, said substances decomposing at the given melting temperature of the metal phase during gas formation. The forming or formed gas bubbles are thereby frozen in the melt and a foam article thus produced.

Furthermore, foaming processes are known in which gas is introduced under the surface of a molten foamable metal, a so-called liquid composite material, and a metal foam produced in this way.

For example, a continuous foaming process of this type is known from WO 91/01387 or EP-483184 B1.

Introducing gas into the liquid metal by means of whirling can also take place according to EP-545957 B1, wherein pores with varying diameters are present in the foam material thus formed and

solidified, from which a material performance results that is difficult to reproduce. Setting the pore size or size distribution in the foam article is thereby not possible to a sufficient extent.

According to US 5,281,251, gas is introduced into the melt by means of a feeding device that is configured in a swirl-like manner and which has gas outlets on the external blade ends. US 5,334,236 discloses a similar embodiment of the gas inlet means or a vibrating or oscillating nozzle.

To obtain an efficient foam formation, it was also proposed (EP- 544291 A1) to add gas to the liquid metal via a number of nozzles in the manner of an oscillating nozzle cam or by means of a vertical nozzle having propeller-type agitators rotating about them for whirling the gas bubbles.

All of the known devices for producing metal foam by introducing gas into a melt have the common disadvantages that pores or gas bubbles with large variations in size are formed and that their size and size distribution cannot be set as desired. This results in often undesirable comparatively high specific weights and insufficiently reproducible material performance of the metal foam material.

It is this that the invention seeks to remedy. An object of the invention is to create a device of the aforementioned type with which gas can be introduced into the melt in the form of pores or bubbles that are adjustable in size and exhibit an almost equal volume. A further object of the invention is to provide a process for producing a desired metal foam.

According to the invention, the gas feed pipe projects so as to protrude into the melt and has a gas outlet cross section with a surface of 0.006 to 0.2 mm as well as a pipe face end of less than 4.0 mm<sup>2</sup> on the projecting end.

The outlet (2) of the gas feed pipe (1) can be configured so as to project into the melt with an overall length (E) of at least five times, preferably of at least 10 times, the value of the largest inside measurement (D2) of the outlet (2). The gas feed pipe (1) can have a circular gas outlet (2) and a pipe face edge or ring-shaped pipe face end (3). The gas feed pipe (1) projecting into the melt (S) can have a spherical, truncated conical or truncated pyramidal outer contour (6) at least in the area of the gas outlet end (2). The angle ( $\alpha$ ), that the production end (61) of the frustum surface (6) with the axis of the gas inlet channel comprises, can have a value of less than 60°, preferably less than 45°.

At least 2, preferably more than 2, gas feed pipes (1, 1', 1''), in particular spaced equidistantly (A1, A2) to one another, preferably more than 10 times that of the projecting measurement (E) of the outlet into the melt, can be arranged in an exchangeable nozzle connection (8) in the melting vessel (9) of metal foaming plants, according to  $A \geq 10 \times E$ .

The invention also provides a device for introducing gas into a melt consisting of foamable metal by means of at least one pipe to produce metal foam, wherein the gas feed pipe projects into the melt so as to protrude and has a gas outlet cross section with a surface of 0.006 to 0.2 mm<sup>2</sup> as well as a pipe face end of less than 4.0 mm<sup>2</sup> at the projecting end, characterized therein that the gas feed pipe consists of a ceramic at least in the area of the projecting end. The ceramic can be an oxide ceramic, in particular an aluminum oxide ceramic.

3a

The invention also provides a process for producing metal foam by injecting gas into a foamable molten metal, characterized therein that a uniformity of the diameter or the size of the respective individual bubbles and the size of the gas bubbles are controlled by a geometric nozzle design and a setting of the flow-in parameters of the gas into the molten metal. The uniformity of the size of the individual bubbles can be obtained by means of the gas feed pipe projecting into the melt and the size of the individual bubbles is controlled by the size of the gas outlet cross section, the size of the feed pipe face end and the level of the gas pressure. The gas can be fed into the melt with a pressure swinging or varying about an average value and/or by oscillating nozzles. The gas can be injected with a pressure of 0.3 - 12 bar, preferably with 0.7 to 5 bar. The molten metal can be made from light metal, preferably from aluminum or an aluminum alloy.

To set the foamable molten metal SiC particles and/or Al<sub>2</sub>O<sub>3</sub> particles as well as other non-metallic particles and/or intermetallic phases can be used. The particles, for stabilizing the metal foam, can have a size of 1 to 50 µm, preferably 3 to 20 µm. The foamable molten metal can be produced with a volumetric weight of particles from 2 to 50 % by volume, preferably 18 to 28 % by volume.

The metal foam can be produced by injecting gas into a foamable molten metal, whereby a uniformity of the diameter or the size of the respective injection and the size of the gas bubbles are controlled, characterized therein that the gas is injected below the melt surface, at least at a distance S (in millimeter) according to  $S = -11.5 + 144.6 \times P^{-0.55}$  wherein P is the numerical value of particles of the melt in % by volume.

3b

The gas can be an oxygen-containing gas, preferably air, in particular essentially pure oxygen.

The invention also provides a flowable metal foam with gas bubbles which are limited by walls consisting of a liquid metal matrix with solid reinforcing particles, characterized therein that the diameter of the largest gas bubble divided by that of the smallest gas bubble gives a value of less than 2.5.

The invention also provides metal foam bodies with spatially uniformly distributed pores, surrounded by a solid wall, wherein the wall consists of a metal matrix and particles embedded therein, characterized therein that the pores are shaped essentially spherical and/or ellipsoidal so as to be closed, whereby the largest diameters of the pores in each case are monomodally distributed and the pores are essentially formed from individual stabilized bubbles and that the inner surfaces of the wall are coated at least partially by an oxide.

More specifically the present invention provides a device for introducing gas into a melt of foamable metal to produce metal foam, the device comprising at least one gas feed pipe having a projecting end, with an end face, for insertion into the melt, wherein the projecting end has a gas outlet with inside measurements producing a cross-sectional area of 0.006 to 0.2 mm<sup>2</sup>, and wherein the end face has a cross-sectional area of less than 4.0 mm<sup>2</sup> at the projecting end.

The present invention also provides a process for producing metal foam, the process comprising the steps of introducing a gas into a foamable molten metal using a device as defined herein.

3c

The present invention also provides a flowable metal foam or a solid metal foam produced by the process defined herein.

The advantages obtained with the invention can essentially be seen therein that stable bubble separation criteria are created at the gas feed pipe during formation of the pores for their specific size.

If gas is introduced into a foamable metal according to the prior art through a bore in a nozzle plate, then, as studies have shown, a bubble is produced whereby an expansion of the bubble adhesion area occurs subsequently about the bore. The time of the separation and the size of the bubble formed thereby in practice on the nozzle plate are not subject to any strict and narrow regularity, so that metal foam with bubbles formed in this way which exhibit various diameters, is formed. If, for example, two or more bores are provided in the nozzle plate for a gas inlet into the liquid metal, then the expansion of the respective bubble adhesion area can proceed on the plate surface so far that the individual bubbles join together while forming an extra large bubble which is contrary to a desired foam formation. As noted above, it has already been attempted to attain a specific gas bubble separation from the nozzle or a distribution of large gas bubbles through a relative movement of the gas inlet in the metal or by whirling, however, this did not result in a desired effect to a sufficient extent.

By means of the geometric design of the gas feed pipe according to the invention, desired and stable gas bubble separation criteria can first be created in the melt, which essentially produce an

- 4 -

equally high individual bubble volume and metal foam formed accordingly.

The construction of the device can advantageously be accomplished in such a way that the outlet of the gas feed pipe is configured so as to project into the melt on a scale of at least five times, preferably of at least ten times, the value of the largest inside dimensions of the outlet. In this way, especially effective stable separation criteria of the bubbles in the melt can be attained.

If, advantageously, the gas feed pipe has a circular gas outlet and a pipe front end or ring-shaped pipe front end, especially economical pipe front designs can be produced for controlling the gas bubble size.

To attain great stability with a small front end of the gas feed pipe and also long service life of the device in foaming operation, it may be advantageous if the gas feed pipe projecting into the melt has a spherical segmental, truncated conical or truncated pyramidal shaped outer contour, at least in the area of the gas outlet end. It is thereby advantageous to configure the outer contour of the gas feed pipe in such a way that the angle which comprises the generating of the frustum surface with the axis of the gas inlet channel, has a value of less than  $60^\circ$ , preferably less than  $45^\circ$ .

From a technical point of view, but also with respect to the performance of the system and the product quality, it can also result in an essential advantage if at least 2, preferably more than 2, gas feed pipes, in particular equally spaced from one another, said space preferably having a value of more than ten times the projection dimension of the outlet or the gas feed pipe

- 5 -

into the melt, are arranged in an interchangeable nozzle connection in the melting vessel of metal foaming plants. In this way, a large high-quality foam amount can be provided at short time intervals which is perhaps desired in an intensive further processing of a starting material, in particular, of larger parts.

Although excellent results can be obtained in individual experiments and in small-scale series production with respect to a uniformity of the gas bubble volumes with a device of the aforementioned type, it was now ascertained during studies for the feasibility of providing metal foam for a large-scale production of components and composite parts for the automobile industry that, during a continuous operation, the geometry of the device can be changed by a melting attack or reaction of the device with a melt, as a result of which it no longer appears given to ensure stable gas bubble separation criteria in a continuous operation.

On the basis of this, the object of the invention is a further design with which stable gas bubble separation criteria during foaming of a molten metal can also be obtained in a continuous operation over long time periods.

The object to create a design of the device with which stable gas bubble separation criteria can also be attained during foaming of a molten metal in a continuous operation over long periods of time is solved therein that the gas feed pipe consists of a ceramic, at least in the area of the projecting end.

The advantages thus attained can be seen, in particular, therein that, in the design of the device according to the invention, the geometry thereof remains essentially unchanged even during prolonged contact with a hot molten metal of at least several

- 6 -

hundred degrees celsius, for which reason stable gas bubble separation criteria can also be obtained during foaming of molten metal with repeated use of the device over long periods of time. The high natural stability and long period of use of the device according to the invention with melting contact now makes it possible to provide metal foams having the same high quality in continuous operation without repairing or replacing a device. In this case, the invention uses the knowledge that the parts of the device made from ceramic, optionally the entire device, react significantly slower in comparison with steel-made devices with molten metal used thusfar and at the same time also enable, with the same geometry, the formation of a hydrophobic system with respect to a gas bubble formation when feeding gas into the melt.

An especially high inactivity and together therewith excellent performance characteristics are obtained in a device according to the invention if the ceramic is an oxide ceramic, in particular an aluminum oxide ceramic.

The further object of the invention to provide a process of the aforementioned type with which high-quality metal foam can be produced by injecting gas into a foamable metal is solved therein that a uniformity of the diameter or the size of the respective individual bubbles and the size of the gas bubbles are controlled by a geometric nozzle design and by setting the inlet parameters of the gas into the molten metal.

The advantages of the metal foam thus obtained can be especially seen therein that bubbles of essentially the same size considerably improve the support criteria of the metal limits during mechanical load with respect to a low specific weight of the foam article and a desired material performance.

- 7 -

When metal foam bodies for a specific use having various diameters of the bubbles that are each of the same size are required, according to the invention, the uniformity of the size of the individual bubbles can be easily obtained by means of the projection of the gas feed pipe into the melt and the size of the individual bubbles can be controlled by the size of the gas outlet cross section, the size of the feed pipe front end and the level of the gas pressure. In fact, if metal foam bodies each have gas bubbles of equal volume, yet of various sizes, then their material performance is also different during forming, as a result of which an article that is best suited therefor can be produced for specific applications.

Extensive studies have shown that the uniformity of the gas bubble size can be further increased if the gas is fed into the melt with a pressure that oscillates about an average value or varies and/or by nozzles that move in an oscillating manner.

Furthermore, technically but also with respect to a high product quality, it can be advantageous if the gas is injected into the foaming metal with a pressure of 0.3 to 12 bar, preferably 0.7 to 5 bar.

Metal foam bodies having especially light or low volumetric weight can be produced if the molten metal is made of a light metal, preferably of aluminum or an aluminum alloy. A greatly demanded material performance with low mass of the part can also be obtained with it.

The foamability of the metal, but also the design of the foam matrix or the foam wall, can be substantially improved if SiC particles and/or  $\text{Al}_2\text{O}_3$  particles are used, as well as other non-

- 8 -

metallic particles and/or particles of intermetallic phases. In this case, it is advantageous with respect to the stability and strength, in particular breaking strength of foam walls, if the particles for stabilizing the metal foam have a size of 1 to 50  $\mu\text{m}$  are used, preferably 3 to 20  $\mu\text{m}$ , and are uniformly distributed in the foam matrix, whereby excellent results can be obtained if a foamable molten metal having a volumetric portion of particles from 2 to 50 % by volume, in particular from 18 to 28 % by volume, is produced in the base metal.

When performing a continuous foaming according to the aforementioned process, it was found that especially with low particle contents of the melts, this can result therein that the particle-affected and metal-affected bubbles situated over the melt surface can burst to a slight extent. As a result, bubbles can join together in the flowable metal foam, so that a solid metal foam can exhibit larger pores formed from two or more individual bubbles, said pores being starting points for a material failure during mechanical stress, in particular during a high compressive-load application at certain points.

The object of the invention to further develop the process in such a way that a partial bursting of bubbles is prevented to a large extent is attained thereby that the gas is injected below the melt surface at least at a distance S (in millimeter) according to

$$S = - 11.5 + 144.6 \times P^{-0.55}$$

wherein P is the numerical value of the particle content of the melt in % by volume.

The advantages obtained by the further development according to the

- 9 -

invention lie, above all, therein that, by providing a rise height according to the invention, the gas bubbles introduced into the molten metal to be foamed must cover a minimum distance in the particle-containing melt when rising to the melt surface, sufficient particles can be accumulated in each of the surfaces of the gas bubbles on said path in order to stabilize the bubbles against bursting as soon as they have crossed the melt surface. In particular, foamable molten metals with a low particle content, e.g. two percent by volume, can thereby now also be easily converted into stable metal foams having a high quality by providing a correspondingly large rise height.

If, as was also found, an oxygen-containing gas, preferably air, in particular essentially pure oxygen, is now injected, the advantageous effects of a minimum rise height of gas bubbles adjusted to the particle content of the melt can now be surprisingly increased, because an intensively acting oxide layer is simultaneously formed on the surface of the particle and metal affected gas bubble.

To provide starting material for making metal foam articles having the desired material performance, the invention aims to create a flowable metal foam with gas bubbles which is limited by walls consisting of a liquid metal matrix with solid reinforcing particles. This object is attained thereby that the diameter of the largest gas bubble divided by the diameter of the smallest gas bubble gives a value of less than 2.5. A flowable metal foam of this type can, by using various agents, be shaped with high accuracy into parts and allowed to solidify whereby, depending on the individual bubble size and ratio value, a specific density of the part and its compression behaviour when acted upon by a compressive stress. Foam parts having a density of 0.09 to 0.11

- 10 -

each experience, for example, a compressive degree of up to 70 % with only slightly increasing compressive stresses of 0.25 to 0.8 MPa.

A metal foam article which withstands both high surface and also high selective mechanical stress is obtained thereby that the pores, in a metal foam of the aforementioned type, are shaped in a closed manner so as to be essentially spherical and/or ellipsoidal, the largest diameters of each of the pores being distributed in a monomodal manner and the pores formed essentially from individual stabilized bubbles and that the inner surfaces of the walls are covered at least partially with an oxide.

With an advantageous monomodal size distribution of spatially uniformly distributed pores with respect to the isotropy of mechanical properties, the metal foam article according to the invention has, in addition, an oxide-reinforced pore wall structure, as a result of which an increased capacity can be obtained in use or the duration of use of building components with a metal foam unit can be increased. Due to formation of the pores in such a way that the pores essentially correspond to individual, stabilized bubbles of a flowable metal foam, a metal foam article according to the invention is suitable for use in components not only with high surface load but also exceptionally with high loads that occur at specific points.

The invention will be described in greater detail in the following with reference to the drawings representing an embodiment each and showing:

Fig. 1      a gas feed pipe

- 11 -

Fig. 2 a gas feed pipe with truncated conical outer contour

Fig. 3 a nozzle connection with several gas feed pipes

Furthermore, an embodiment of the invention is described in greater detail with reference to drawings, showing:

Fig. 4 the dependency of the minimum rise height provided according to the invention of the particle content of the melt.

Fig. 5 the pore size distribution of a metal foam article according to the invention.

A gas feed pipe 1 is shown in Fig. 1 which projects with an overall length E into a melt. The gas feed pipe 1 has a constant wall thickness between inner surface 4 and outer surface 5 with a pipe face 3 which projects into the melt S.

Fig. 2 shows a gas feed pipe 1 with a projection size E into a melt S, said pipe 1 having a truncated conical or truncated pyramidal outer contour 6 which has an angle to the axis 7 of a gas inlet channel in the extension. With a design of this type for a gas feed pipe 1, a pipe face end 3 having the lowest surface content up to a face edge can be formed with high stability and strength of the base part.

A design with a nozzle connection 8, which is arranged in a wall 9 of a melting vessel, preferably so as to be detachable, can be seen in Fig. 3. Three gas feed pipes 1, 1', 1" projecting into a melt S are spaced from one another at a distance  $A_1$  and  $A_2$  in the nozzle connection. Nozzle connections 8 of this type which are easily exchangeable are preferably used when metal foams are to be

- 12 -

produced with essentially equal individual bubble volumes, yet with various bubble sizes because the formation criteria can be quickly changed: size of the gas outlet cross section and size of the gas feed pipe face.

The bubble formation mechanisms are to be briefly described again with reference to the schematic drawings:

If gas is injected into a melt  $S$ , then a convex arch is formed in it at the outlet 2 of the feed hole 1. About this increasing arch, the melt hangs on the surrounding surface of the gas outlet. Because the contact surface system of the melt/wall is now present as a hydrophobic system, the adhesiveness of the liquid metal is slight about the gas outlet, which results in separation phenomena and areal shifting of the gas bubble limit on the wall. As a result, the separation conditions for the gas bubble are largely uncertain which can result in various bubble sizes. If bubbles are to be produced by means of several adjacent outlets, then they join together in most cases, as a result of which a desired foaming is prevented or an irregular bubble structure of the metal foam is formed.

If, for example, a gas feed pipe 1 projecting according to the invention now has an inside diameter  $D_2$  and a gas outlet cross section 2 as well as an outside diameter  $D_1$ , then the measurement of the pipe face end 3 results.

When introducing gas into the melt, however, the gas bubble limit can only travel up to the outer edge of the pipe face end 3, as a result of which it essentially affects the separation criteria. Adjacent gas feed pipes 1, 1', 1" that project into a foamable melt  $S$  also form defined separation criteria for gas bubbles due to the rebounding surfaces on the outer edges of the face ends 3, so that the joining and formation of large bubbles is largely excluded.

- 13 -

In an extensive series of tests, various particle-containing aluminum alloys, e.g. AlSi7Mg, an aluminum alloy also known as A 356 with, in addition to aluminum, essentially 7 % by weight silicon and 1 % by weight magnesium or e.g. AA 6061 (aluminum alloy with a composition according to the standard Aluminum Association Number 6061), were melted in a crucible, whereby the particle content in the melt was set, optionally, by adding a particle-free alloy corresponding to one in the chemical composition. Gas was then fed into the particle-containing melt. In all tests, it was always introduced via an individual nozzle body having an outlet, whereby nozzle bodies consisting of chromium-nickel-steel and of ceramic were used.

In a first series of tests, the durability of various nozzle bodies was studied. When carrying out five foaming tests each over a period of 20 seconds to 45 minutes with chromium-nickel-steel nozzles, on the one hand, and with aluminum oxide nozzles, on the other hand, which were used for more than about 2 minutes, a change in the shape of the gas outlet due to a melt attack could be ascertained optically. Accordingly, the metal foam produced at the start and at the end of the foaming process and removed from the melt surface had various pore diameters. In contrast thereto, no changes of this type in the geometry were visible when using the nozzle bodies consisting of aluminum oxide, even with continuous use of more than 45 minutes. Accordingly, metal foam with equivalent pore properties could be produced over the entire testing period. Other ceramic materials, such as  $\text{SiO}_2$  or  $\text{SiO}_2/\text{Al}_2\text{O}_3$ , can also be used advantageously vis-à-vis steels; however, the longest period of use was comparatively obtained with nozzle bodies

- 14 -

made of  $\text{Al}_2\text{O}_3$ .

In a second series of tests, the rise height  $S$  of the introduced gas was varied with nozzle bodies made of aluminum oxide with fixed particle content  $P$  of the melt and the quality of the metal foams formed with the various gas introduction depths studied. The following behaviour was observed with reference to Fig. 4: With a low particle content  $P$  of the melt, e.g. 2 % by volume, at a low rise height  $S$ , metal foam can be formed in which, in a cross sectional view, pores are present that are formed from at least two bubbles. Such pores can be easily recognized due to the fact that they are formed ellipsoidally with a high ratio of the longer to the shorter axis. A behaviour of this type can be found in the studied particle contents in the area of the rise height of Fig. 4. However, as soon as the rise height  $S$  is no longer in the area A of Fig. 4 with a given particle content  $P$ , but is increased in such a way that they fall in area B, a metal foam can be produced in which the bubbles can accumulate sufficient particles on the surface due to the increased rise path, in order to become stabilized against bursting in the liquid metal foam. The necessary rise heights determined experimentally for the essentially complete bubble stabilization are shown in Fig. 4 for various particle contents in the form of triangles. A compensating curve, adapted to the experimental data, of the general formula

$$Y = a + X^b$$

represents the line separating area A and area B.

When the minimum rise height was maintained, more than 95%, partially more than 99%, pores which correspond to individual gas bubbles were ascertained in the metal foam in cross section. Fig.

- 15 -

5 shows the pore size distribution of a metal foam which was produced while maintaining the foaming conditions according to the invention. As can be seen with reference to the histogram in Fig. 5, in a monomodal distribution of the pore sizes at an average value of 4 mm, the portion of pores with about 6 mm is, proportionately, only slightly higher than that with 2 mm, i.e. the pore sizes are distributed on both sides of an average value to almost the same extent or the same frequency.

In a third series of tests, the effects of the injected gases on the material composition and the material properties were studied. In this case, it was unexpectedly shown within the scope of secondary electronic microscopic (SEM) studies that, when using oxygen-containing gases, such as cost-effective air, an additional layer of oxide is formed on the pore surfaces in partial areas. The oxide layer acts in a reinforcing manner on the metal foam, as a 5 to 7 % increase of the shaping energy required for compression of the metal foam bodies according to the invention to half the volume. A further increased rise of the same shaping energy of a total of about 10% was observed when using pure oxygen as foaming gas. In these cases, the inner surfaces of the walls are essentially fully covered with an oxide layer, i.e. at least 90%, as could be shown by means of SEM photos.

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

1. A device for feeding gas into a melt of foamable metal, the device comprising at least one gas feed pipe end projecting into the melt, the gas feed pipe end having an outer and inner circumference defining:

(i) a gas outlet with a cross-sectional area of 0.006 to 0.2 mm<sup>2</sup> within the inner circumference; and

(ii) a cross-sectional end face of the feed pipe end covering an area of less than 4.0 mm<sup>2</sup> between the inner and outer circumference;

whereby the cross-sectional area within the inner circumference and the area of the cross-sectional end face between the inner and outer circumference cooperate to determine the size of individual bubbles in the melt.

2. A device according to claim 1, wherein the outlet of each gas feed pipe end is configured so as to project into the melt with an overall length of at least five times the value of the largest diameter of the cross-sectional area of the outlet.

3. A device according to claim 2, wherein the overall length is at least 10 times the value of the largest diameter of the cross-sectional area of the outlet.

4. A device according to claim 1, 2 or 3, wherein the gas feed pipe end has a circular gas outlet and the end face of the gas feed pipe end is ring-shaped.

5. A device according to any one of claims 1 to 4, wherein the gas feed pipe end has a spherical segment,

truncated conical or truncated pyramidal outer contour in the area of the gas outlet.

6. A device according to claim 5, wherein an inclined edge of the truncated conical or truncated pyramidal outer contour, which is inclined relative to a truncated edge, creates an angle of less than  $60^\circ$  with the axis of the gas outlet.

7. A device according to claim 6, wherein the angle is less than  $45^\circ$ .

8. A device according to any one of claims 1 to 7, wherein at least two gas feed pipe ends are arranged in an exchangeable nozzle arrangement or plate.

9. A device according to claim 8, wherein there are three gas feed pipe ends.

10. A device according to claim 8 or 9, wherein the gas feed pipe ends are spaced equidistantly.

11. A device according to claim 8, 9 or 10, wherein the gas feed pipe ends are spaced apart by a distance that is at least ten times the length of the gas feed pipe ends projecting into the melt.

12. A device according to any one of claims 1 to 11, wherein the gas feed pipe ends comprise a ceramic material.

13. A device according to claim 12, wherein the ceramic material is an oxide ceramic material.

14. A device according to claim 13, wherein the oxide ceramic material is an aluminum oxide ceramic material.

15. A process for producing metal foam, the process comprising the step of:

introducing a gas into a foamable molten metal using a device as defined in any one of claims 1 to 14.

16. A process according to claim 15, wherein gas pressure is between 0.3 and 12 bar.

17. A process according to claim 16, wherein gas pressure is between 0.7 and 5 bar.

18. A process according to claim 16 or 17, wherein the gas pressure varies about an average value.

19. A process according to any one of claims 15 to 18, wherein the device is moved in an oscillating manner during introduction of the gas.

20. A process according to any one of claims 15 to 19, wherein the molten metal is a light metal.

21. A process according to claim 20, wherein the metal is aluminum or an aluminum alloy.

22. A process according to any one of claims 15 to 21, wherein the gas is injected below the molten metal surface, at least at a distance S (in millimeter) according to

$$S = - 11.5 + 144.6 \times P^{-0.55}$$

wherein P is the numerical value of particles of the melt in % by volume.

23. A process according to any one of claims 15 to 22, wherein the molten metal further comprises at least one substance selected from the group consisting of SiC particles and Al<sub>2</sub>O<sub>3</sub> particles.

24. A process according to any one of claims 15 to 22, wherein the molten metal further comprises at least one substance selected from the group consisting of non-metallic particles and particles of intermetallic phases.

25. Process according to claim 23 or 24, wherein the particles have a diameter of 1 to 50 µm.

26. A process according to claim 25, wherein the diameter is 3 to 20 µm.

27. A process according to any one of claims 23 to 26, wherein the volumetric amount of particles is from 2 to 50 % by volume.

28. A process according to claim 27, wherein the volumetric amount of particles is from 18 to 28 % by volume.

29. A process according to any one of claims 15 to 28, wherein the gas is an oxygen-containing gas.

30. A process according to claim 29, wherein the gas is air.

31. A process according to claim 29, wherein the gas is substantially pure oxygen.

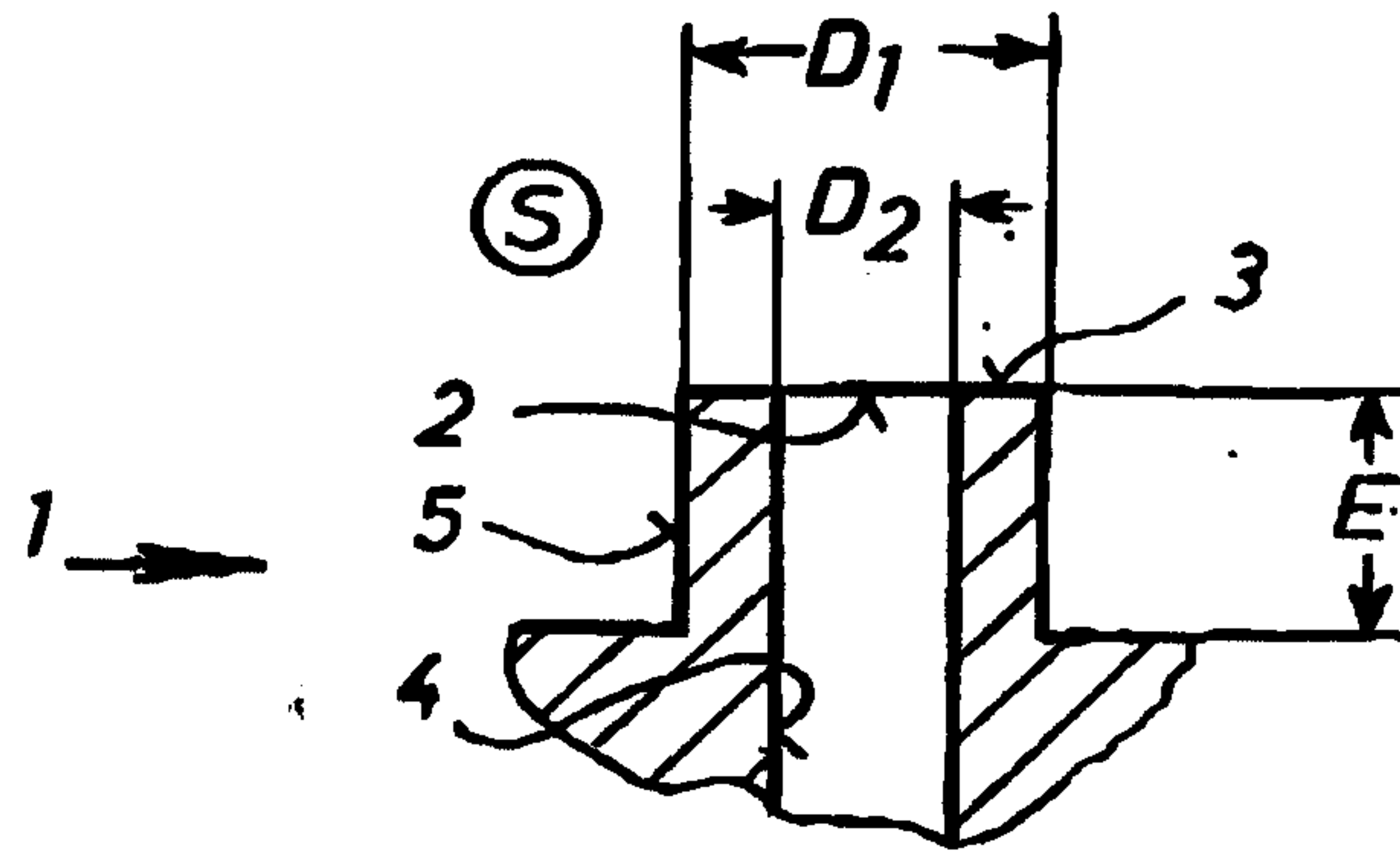


Fig. 1

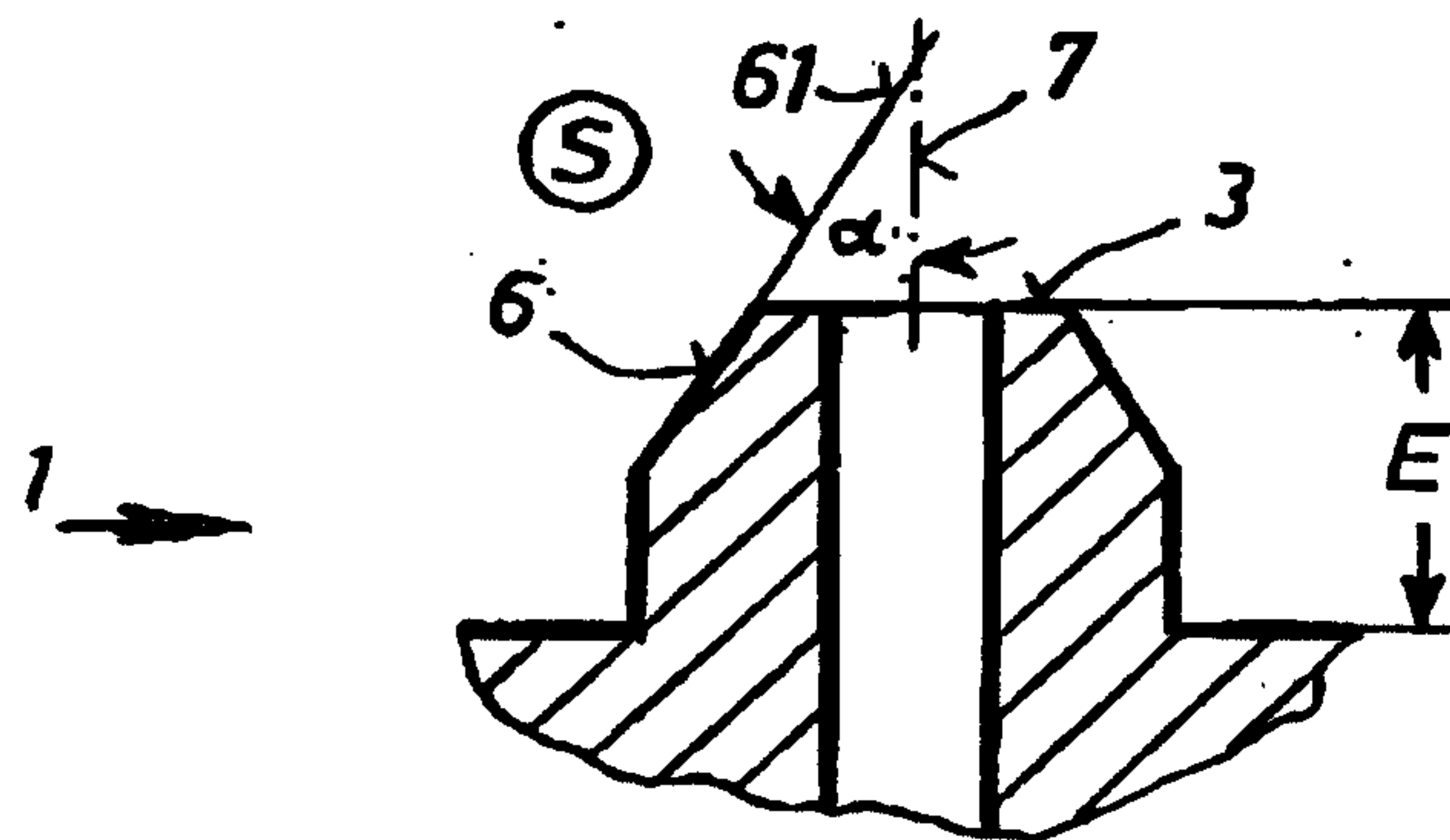


Fig. 2

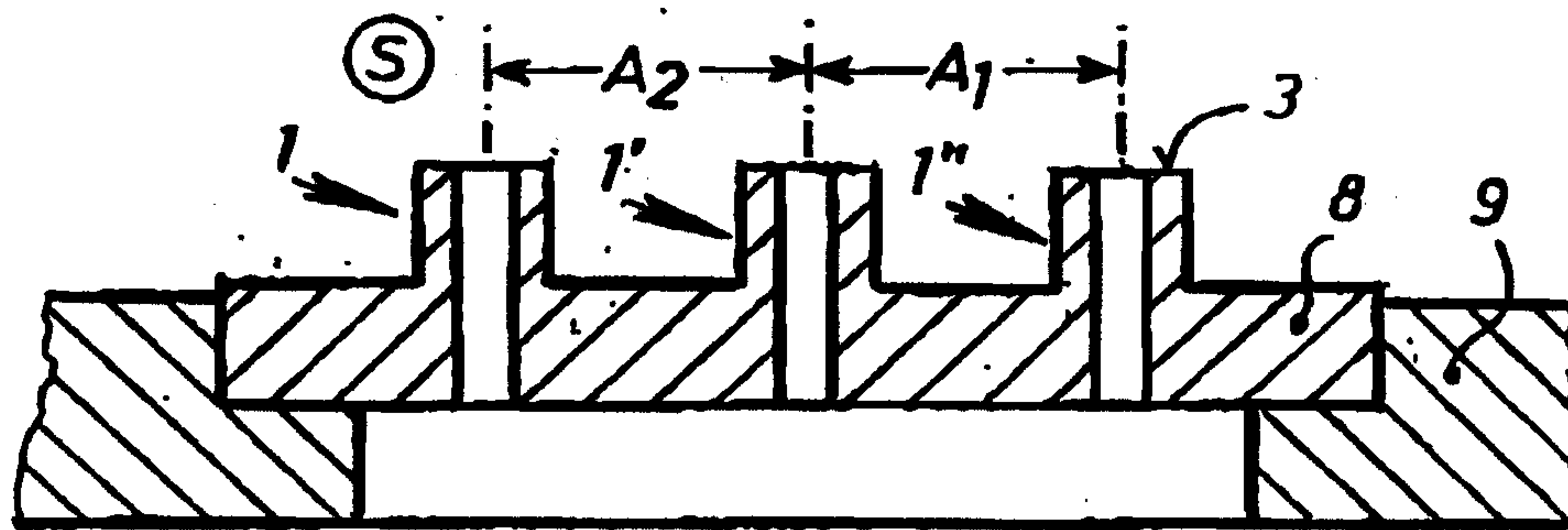
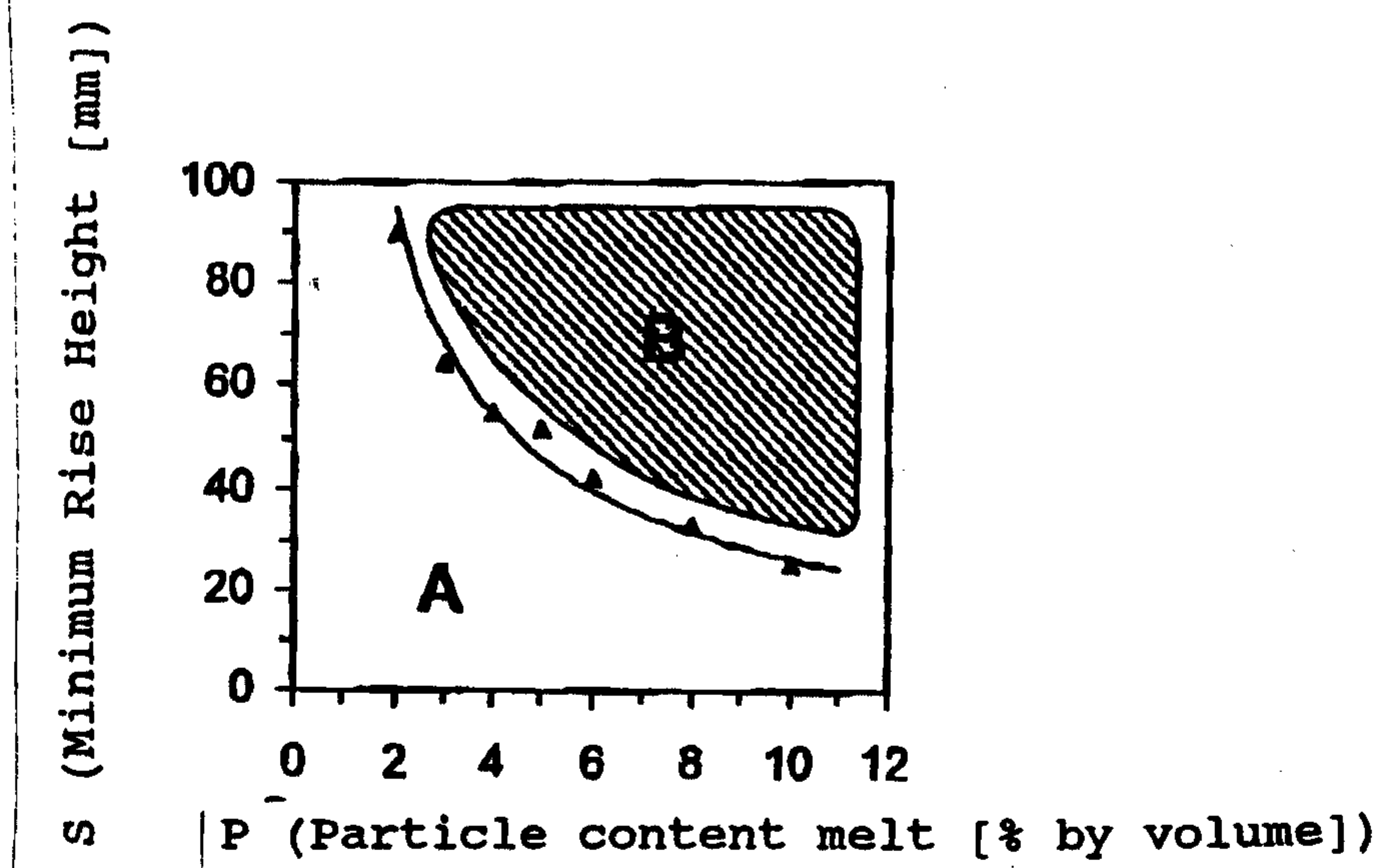
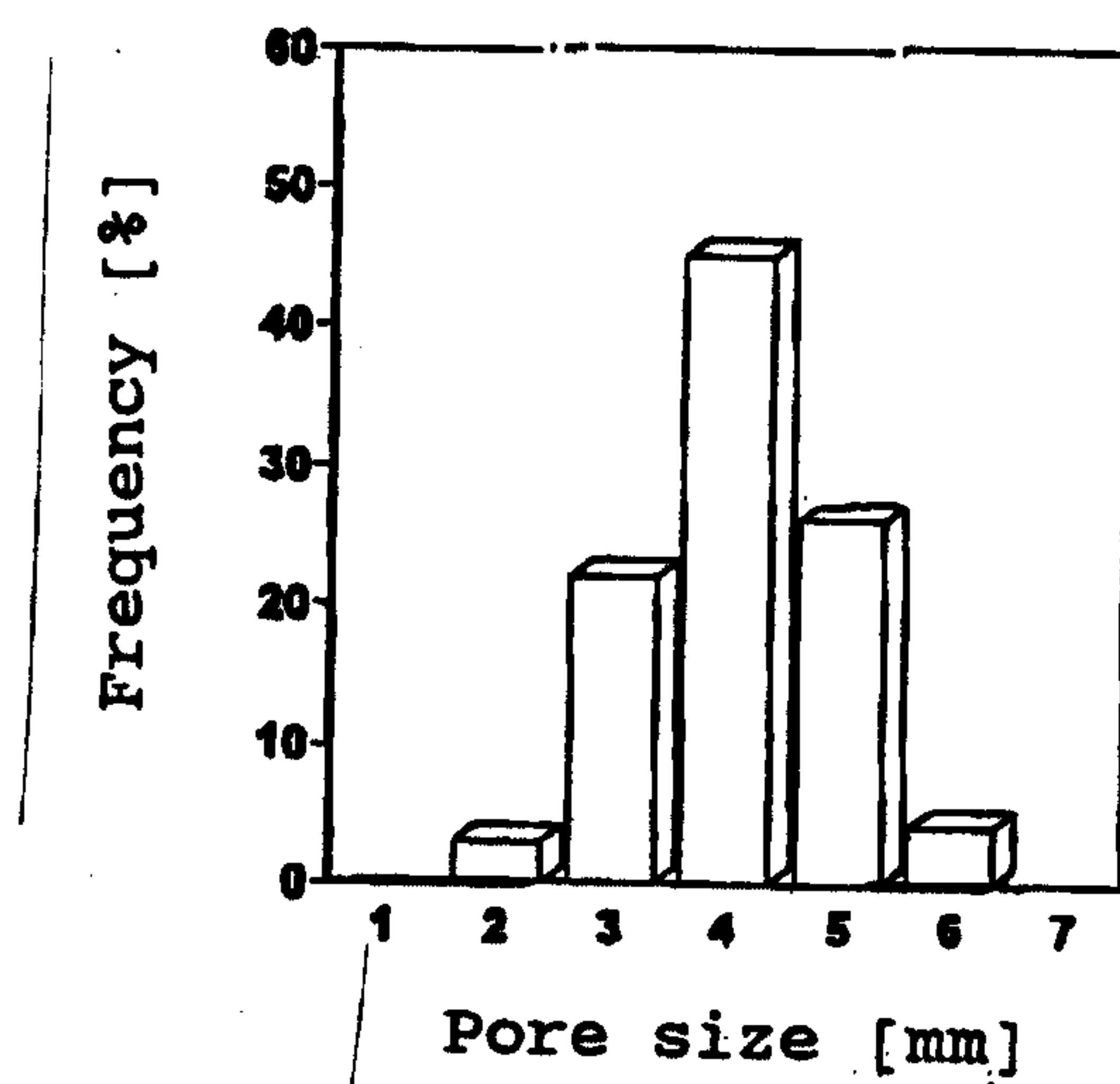


Fig. 3

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**Fig. 4****Fig. 5**

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