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54	TITLE OF INVENTION
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A method of producing a metal body by coalescence and the metal body produced

57	ABSTRACT (NOT MORE THAN 150 WORDS)
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The sheet(s) containing the abstract is/are attached.

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The figure of the drawing to which the abstract refers is attached.

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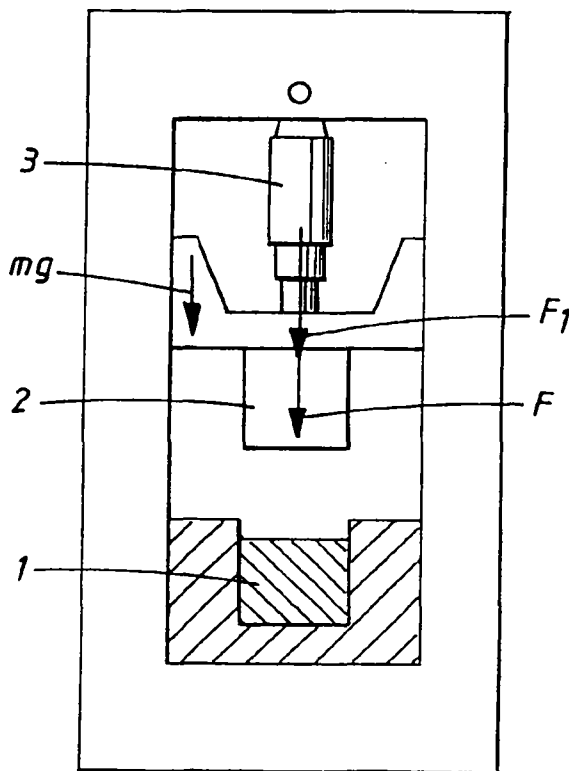
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(54) Title: A METHOD OF PRODUCING A METAL BODY BY COALESCENCE AND THE METAL BODY PRODUCED



(57) Abstract: A method of producing a metal body by coalescence, wherein the method comprises the steps of a) filling a pre-compacting mould with metal material in the form of powder, pellets, grains and the like, b) pre-compacting the material at least once and c) compressing the material in a compression mould by at least one stroke, where a striking unit emits enough kinetic energy to form the body when striking the material inserted in the compression mould, causing coalescence of the material. A method of producing a metal body by coalescence, wherein the method comprises compressing material in the form of a solid metal body in a compression mould by at least one stroke, where a striking unit emits enough energy to cause coalescence of the material in the body. Products obtained by the inventive methods.

A METHOD OF PRODUCING A METAL BODY BY COALESCENCE AND THE METAL BODY PRODUCED

5 The invention concerns a method of producing a metal body by coalescence as well as the metal body produced by this method.

STATE OF THE ART

10 In WO-A1-9700751, an impact machine and a method of cutting rods with the machine is described. The document also describes a method of deforming a metal body. The method utilises the machine described in the document and is characterised in that a metallic material either in solid form or in the form of powder such as grains, pellets and the like, is fixed preferably at the end of a mould, holder or the like and that the material is subjected to adiabatic coalescence by a striking
15 unit such as an impact ram, the motion of the ram being effected by a liquid. The machine is thoroughly described in the WO document.

In WO-A1-9700751, shaping of components, such as spheres, is described. A metal powder is supplied to a tool divided in two parts, and the powder is supplied
20 through a connecting tube. The metal powder has preferably been gas-atomized. A rod passing through the connecting tube is subjected to impact from the percussion machine in order to influence the material enclosed in the spherical mould. However, it is not shown in any embodiment specifying parameters for how a body is produced according to this method.

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The compacting according to this document is performed in several steps, e.g. three. These steps are performed very quickly and the three strokes are performed as described below.

Stroke 1: an extremely light stroke, which forces out most of the air from the
30 powder and orients the powder particles to ensure that there are no great irregularities.

Stroke 2: a stroke with very high energy density and high impact velocity, for local adiabatic coalescence of the powder particles so that they are compressed against each other to extremely high density. The local temperature increase of each particle is dependent on the degree of deformation during the stroke.

- 5 Stroke 3: a stroke with medium-high energy and with high contact energy for final shaping of the substantially compact material body. The compacted body can thereafter be sintered.

10 In SE 9803956-3 a method and a device for deformation of a material body are described. This is substantially a development of the invention described in WO-A1-9700751. In the method according to the Swedish application, the striking unit is brought to the material by such a velocity that at least one rebounding blow of the striking unit is generated, wherein the rebounding blow is counteracted whereby at least one further stroke of the striking unit is generated.

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The strokes according to the method in the WO document, give a locally very high temperature increase in the material, which can lead to phase changes in the material during the heating or cooling. When using the counteracting of the rebounding blows and when at least one further stroke is generated, this stroke
20 contributes to the wave going back and forth and being generated by the kinetic energy of the first stroke, proceeding during a longer period. This leads to further deformation of the material and with a lower impulse than would have been necessary without the counteracting. It has now shown that the machine according to these mentioned documents does not work so well. For example are the time
25 intervals between the strokes, which they mention, not possible to obtain. Further, no embodiments showing that a body could be formed is shown.

OBJECT OF THE INVENTION

30 The object of the present invention is to achieve a process for efficient production of products from metal at a low cost. These products may be both medical devices

such as medical implants, instruments, for example surgical knives, or diagnostic equipment, or non medical devices such as ball bearings, cutting tools, wear surfaces, or electrical components. Another object is to achieve a metal product of the described type.

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It should also be possible to perform the new process at a much lower velocity than the processes described in the above documents. Further, the process should not be limited to using the above described machine.

10 SHORT DESCRIPTION OF THE INVENTION

It has surprisingly been found that it is possible to compress different metal and metal alloys according to the new method defined in claim 1. The material is for example in the form of powder, pellets, grains and the like and is filled in a mould,
15 pre-compacted and compressed by at least one stroke. The machine to use in the method may be the one described in WO-A1-9700751 and SE 9803956-3.

The method according to the invention utilises hydraulics in the percussion machine, which is the machine utilised in WO-A1-9700751 and SE 9803956-3.

20 When using pure hydraulic means in the machine, the striking unit can be given such movement that, upon impact with the material to be compressed, it emits sufficient energy at sufficient speed for coalescence to be achieved. This coalescence may be adiabatic. A stroke is carried out quickly and for some materials the wave in the material decay in between 5 and 15 milliseconds. The
25 hydraulic use also gives a better sequence control and lower running costs compared to the use of compressed air. A spring-actuated percussion machine will be more complicated to use and will give rise to long setting times and poor flexibility when integrating it with other machines. The method according to the invention will thus be less expensive and easier to carry out. The optimal machine
30 has a large press for pre-compacting and post-compacting and a small striking unit with high speed. Machines according to such a construction are therefore probably

more interesting to use. Different machines could also be used, one for the pre-compacting and post-compacting and one for the compression.

SHORT DESCRIPTION OF THE DRAWINGS

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On the enclosed drawings

Figure 1 shows a cross sectional view of a device for deformation of a material in the form of a powder, pellets, grains and the like.

Figure 2-24 and 26-47 shows relative density as a function of total impact energy, impact energy per mass, impact velocity and number of strokes, which show the result from the Experiments.

Figure 25 shows total porosity (5) as a function of total impact energy.

DETAILED DESCRIPTION OF THE INVENTION

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The invention concerns a method of producing a metal body by coalescence, wherein the method comprises the steps of

- a) filling a pre-compacting mould with metal material in the form of powder, pellets, grains and the like,
- 20 b) pre-compacting the material at least once and
- c) compressing the material in a compression mould by at least one stroke, where a striking unit emits enough kinetic energy to form the body when striking the material inserted in the compression mould, causing coalescence of the material.

25 The pre-compacting mould may be the same as the compression mould, which means that the material does not have to be moved between the step b) and c). It is also possible to use different moulds and move the material between the steps b) and c) from the pre-compacting mould to the compression mould. This could only be done if a body is formed of the material in the pre-compacting step.

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The device in Figure 1 comprises a striking unit 2. The material in Figure 1 is in the form of powder, pellets, grains or the like. The device is arranged with a striking unit 3, which with a powerful impact may achieve an immediate and relatively large deformation of the material body 1. The invention also refers to compression of a body, which will be described below. In such a case, a solid body 1, such as a solid homogeneous metal body, would be placed in a mould.

The striking unit 2 is so arranged, that, under influence of the gravitation force, which acts thereon, it accelerates against the material 1. The mass m of the striking unit 2 is preferably essentially larger than the mass of the material 1. By that, the need of a high impact velocity of the striking unit 2 can be reduced somewhat. The striking unit 2 is allowed to hit the material 1, and the striking unit 2 emits enough kinetic energy to compress and form the body when striking the material in the compression mould. This causes a local coalescence and thereby a consequent deformation of the material 1 is achieved. The deformation of the material 1 is plastic and consequently permanent. Waves or vibrations are generated in the material 1 in the direction of the impact direction of the striking unit 2. These waves or vibrations have high kinetic energy and will activate slip planes in the material and also cause relative displacement of the grains of the powder. It is likely that the coalescence is an adiabatic coalescence. The local increase in temperature develops spot welding (inter-particular melting) in the material which increases the density.

The pre-compaction is a very important step. This is done in order to drive out air and orient the particles in the material. The pre-compaction step is much slower than the compression step, and therefore it is easier to drive out the air. The compression step, which is done very quickly, may not have the same possibility to drive out air. In such case, the air may be enclosed in the produced body, which is a disadvantage. The pre-compaction is performed at a minimum pressure enough to obtain a maximum grade of packing of the particles which results in a maximum contact surface between the particles. This is material dependent and depends on the softness and melting point of the material.

The pre-compacting step in the Examples has been performed by compacting with about 117680 N axial load. This is done in the pre-compacting mould or the final mould. According to the examples in this description, this has been done in a
5 cylindrical mould, which is a part of the tool, and has a circular cross section with a diameter of 30 mm, and the area of this cross section is about 7 cm². This means that a pressure of about 1.7×10^8 N/m² has been used. For stainless steel is the material pre-compacted with a pressure of at least about 0.25×10^8 N/m², and more preferred with a pressure of at least about 0.6×10^8 N/m². This is material
10 dependent and for a softer metal could it be enough to compact at a pressure of about 2000 N/m². Other possible values are 1.0×10^8 N/m², 1.5×10^8 N/m². The studies made in this application are made in air and at room temperature. All values obtained in the studies are thus achieved in air and room temperature. It may be possible to use lower pressures if vacuum or heated material is used. The height of
15 the cylinder is 60 mm. In the claims is referred to a striking area and this area is the area of the circular cross section of the striking unit which acts on the material in the mould. The striking area in this case is the cross section area.

In the claims is also referred to the cylindrical mould used in the Examples. In this
20 mould is the area of the striking area and the area of the cross section of the cylindrical mould the same. However, other constructions of the moulds could be used, such as a spherical mould. In such a mould, the striking area would be less than the cross section of the spherical mould.

25 The invention further comprises a method of producing a metal body by coalescence, wherein the method comprises compressing material in the form of a solid metal body in a compression mould by at least one stroke, where a striking unit emits enough energy to cause coalescence of the material in the body. Slip planes are activated during a large local temperature increase in the material,
30 whereby the deformation is achieved. The method also comprises deforming the body.

The method according to the invention could be described in the following way.

1) Powder is pressed to a green body, the body is compressed by impact to a (semi)solid body and thereafter may an energy retention be achieved in the body by a post-compacting. The process, which could be described as Dynamic Forging Impact Energy Retention (DFIER) involves three mains steps.

a) Pressuring

The pressing step is very much like cold and hot pressing. The intention is to get a green body from powder. It has turned out to be most beneficial to perform two compactions of the powder. One compaction alone gives about 2-3% lower density than two consecutive compactions of the powder. This step is the preparation of the powder by evacuation of the air and orient the powder particles in a beneficial way. The density values of the green body is more or less the same as for normal cold and hot pressuring.

b) Impact

The impact step is the actual high-speed step, where a striking unit strikes the powder with a defined area. A material wave starts off in the powder and interparticular melting takes place between the powder particles. Velocity of the striking unit seems to have an important role only during a very short time initially. The mass of the powder and the properties of the material decides the extent of the interparticular melting taking place.

c) Energy retention

The energy retention step aims at keeping the delivered energy inside the solid body produced. It is physically a compaction with at least the same pressure as the pre-compaction of the powder. The result is an increase of the density of the produced body by about 1-2%. It is performed by letting the striking unit stay in place on the solid body after the impact and press with at least the same pressure as at pre-compaction, or release after the impact step. The idea is that more transformations of the powder will take place in the produced body.

- According to the method, the compression strokes emit a total energy corresponding to at least 100 Nm in a cylindrical tool having a striking area of 7 cm² in air and at room temperature. Other total energy levels may be at least 300, 600, 1000, 1500, 2000, 2500, 3000 and 3500 Nm. Energy levels of at least 10 000, 20 000 Nm may also be used. There is a new machine, which has the capacity to strike with 60 000 Nm in one stroke. Of course such high values may also be used. And if several such strikes are used, the total amount of energy may reach several 100 000 Nm. The energy levels depend on the material used, and in which application the body produced will be used. Different energy levels for one material will give different relative densities of the material body. The higher energy level, the more dense material will be obtained. Different material will need different energy levels to get the same density. This depends on for example the hardness of the material and the melting point of the material.
- 15 According to the method, the compression strokes emit an energy per mass corresponding to at least 5 Nm/g in a cylindrical tool having a striking area of 7 cm² in air and at room temperature. Other energies per mass may be at least 20 Nm/g, 50 Nm/g, 100 Nm/g, 150 Nm/g, 200 Nm/g, 250 Nm/g, 350 Nm/g and 450 Nm/g.
- 20 With the same energy per mass the relative density will reach a higher level for a greater mass and a lower for a smaller mass. The difference between these relative densities of different masses is biggest with lower energies per mass. This is shown in a mass parameter study for stainless steel in the Examples, and can be shown in Figure 26 where the relative density as a function of impact energy per mass is
- 25 shown. For the sample of 2x28 g, a higher density is obtained for lower energy per mass, compared to the sample of 0.25x28 g, which gets a lower density at the same energy per mass. It can also be seen in Figure 27, where the relative density as a function of the total impact energy is shown. For the mass of 2x28 g is seen, that for a relative density of about 80 % is obtained at a total energy of 625 Nm,
- 30 corresponding to 11 Nm/g. The total energy needed for the sample of 0.25x28 g to obtain a relative density of 80 % is about 220 Nm, corresponding to 35 Nm/g. Thus,

a lower energy per mass is needed for the higher mass to obtain the same relative density.

For the samples tested in the Examples in the mass parameter study, the result is the following. When essentially higher densities are obtained, the method is not depending on the energy per mass, but the total energy seems to be independent of the mass. Thus, the same total energy for the compression strokes gives about the same density for a produced body irrespective of the weight. In Figure 27, the graphs for all the masses are separated for essentially low densities and they are getting closer to each other at essentially higher densities. This means that the total energy is irrespective of the mass at essentially higher densities. This is shown for stainless steel and the limit between the separation of the curves and the meeting of the curves, or high and low densities, are about 90 %, and the total energy is about 1500 Nm at 90 % for stainless steel.

These values will vary dependent on what material is used. A person skilled in the art will be able to test at what values the mass dependency will be valid and when the mass independence will start to be valid. The changeover of the densities from the lower to higher densities will vary depending on the material. These values are approximate.

The energy level needs to be amended and adapted to the form and construction of the mould. If for example, the mould is spherical, another energy level will be needed. A person skilled in the art will be able to test what energy level is needed with a special form, with the help and direction of the values given above. The energy level depends on what the body will be used for, i.e. which relative density is desired, the geometry of the mould and the properties of the material. The striking unit must emit enough kinetic energy to form a body when striking the material inserted in the compression mould. With a higher velocity of the stroke, more vibrations, increased friction between particles, increased local heat, and increased interparticular melting of the material will be achieved. The bigger the stroke area

is, the more vibrations are achieved. There is a limit where more energy will be delivered to the tool than to the material. Therefore, there is also an optimum for the height of the material.

- 5 When a powder of a metal material is inserted in a mould and the material is struck by a striking unit, a coalescence is achieved in the powder material and the material will float. A probable explanation is that the coalescence in the material arises from waves being generated back and forth at the moment when the striking unit rebounds from the material body or the material in the mould. These waves give rise
- 10 to a kinetic energy in the material body. Due to the transmitted energy a local increase in temperature occurs, and enables the particles to soften, deform and the surface of the particles will melt. The inter-particle melting enables the particles to re-solidify together and dense material can be obtained. This also affects the smoothness of the body surface. The more a material is compressed by the
- 15 coalescence technique, the smoother surface is obtained. The porosity of the material and the surface is also affected by the method. If a porous surface or body is desired, the material should not be compressed as much as if a less porous surface or body is desired.
- 20 The individual strokes affect material orientation, driving out air, pre-moulding, coalescence, tool filling and final calibration. It has been noted that the back and forth going waves travels essentially in the stroke direction of the striking unit, i. e. from the surface of the material body which is hit by the striking unit to the surface which is placed against the bottom of the mould and then back.
- 25 What has been described above about the energy transformation and wave generation also refer to a solid body. In the present invention a solid body is a body where the target density for specific applications has been achieved.
- 30 The striking unit preferably has a velocity of at least 0.1 m/s or at least 1.5 m/s during the stroke in order to give the impact the required energy level. Much lower

velocities may be used than according to the technique in the prior art. The velocity depends on the weight of the striking unit and what energy is desired. The total energy level in the compression step is at least about 100 to 4000 Nm. But much higher energy levels may be used. By total energy is meant the energy level for all strokes added together. The striking unit makes at least one stroke or a number of consecutive strokes. The interval between the strokes according to the Examples was 0.4 and 0.8 seconds. For example at least two strikes may be used. According to the Examples one stroke has shown promising results. These Examples were performed in air and at room temperature. If for example vacuum and heat or some other improving treating is used, perhaps even lower energies may be used to obtain good relative densities.

The metal may be compressed to a relative density of 70 %, preferably 75 %. More preferred relative densities are also 80 % and 85 %. Other preferred densities are 90 to 100 %. However, other relative densities are also possible. If a green body is to be produced, it could be enough with a relative density of about 50-60 %. Low bearing implant desires a relative density of 90 to 100 % and in some biomaterials it is good with some porosity. If a porosity of at most 5 % is obtained and this is sufficient for the use, no further post-processing is necessary. This may be the choice for certain applications. If a relative density of less than 95 % is obtained, and this is not enough, the process need to continue with further processing such as sintering. Several manufacturing steps have even in this case been cut compared to conventional manufacturing methods.

The method also comprises pre-compacting the material at least twice. It has been shown in the Examples that this could be advantageous in order to get a high relative density compared to strokes used with the same total energy and only one pre-compacting. Two compactations give about 1-5 % higher density than one compacting depending on the material used. The increase may be even higher for other materials. When pre-compacting twice, the compacting steps are performed

with a small interval between, such as about 5 seconds. About the same pressure may be used in the second pre-compacting.

- Further, the method may also comprise a step of compacting the material at least once after the compression step. This has also shown to give very good results. The post-compacting should be carried out at at least the same pressure as the pre-compacting pressure, i.e. $0,25 \times 10^8 \text{ N/m}^2$. Other possible values are $1.0 \times 10^8 \text{ N/m}^2$. Higher post-compacting pressures are also desired, such as a pressure which is twice the pressure of the pre-compacting pressure. For stainless steel is the pre-compacting pressure at least about 0.25 N/m^2 and this would be the smallest post-compacting pressure for stainless steel. The pre-compacting value has to be tested out for every material. An after compacting effect the sample differently than a pre-compacting. The transmitted energy, which increases the local temperature between the powder particles from the stroke, is conserved for a longer time and can effect the sample to consolidate for a longer period after the stroke. The energy is kept inside the solid body produced. Probably is the "lifetime" for the material wave in the sample increased and can affect the sample for a longer period and more particles can melt together. The after compaction or post-compaction is performed by letting the striking unit stay in place on the solid body after the impact and press with at least the same pressure as at pre-compacting, i.e. at least about 0.25 N/m^2 for stainless steel. More transformations of the powder will take place in the produced body. The result is an increase of the density of the produced body by about 1-4 % and is also material dependent.
- When using pre-compacting and/or after compacting, it could be possible to use lighter strokes and higher pre- and/or after compacting, which would lead to saving of the tools, since lower energy levels could be used. This depends on the intended use and what material is used. It could also be a way to get a higher relative density.
- To get improved relative density it is also possible to pre-process the material before the process. The powder could be soft annealed to soften the powder, which

could make the powder easier to compact. Another preparation process of the powder could be to pre-heat the powder to ~200-300 °C or higher depending on what material type to pre-heat. The powder could be pre-heated to a temperature which is close to the melting temperature of the material. Suitable ways of pre-heating may be used, such as normal heating of the powder in an oven. One way is to conduct electrical current through the powder in order to heat the powder. In order to get a more dense material during the pre-compacting step vacuum or inert gas could be used. This would have the effect that air is not enclosed in the material in the same extent during the process.

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The body may according to another embodiment of the invention be heated and/or sintered any time after compression or post-compacting. A post-heating is used to relax the bindings in the material (obtained by increased binding strain). A lower sintering temperature may be used owing to the fact that the compacted body has a higher density than compacts obtained by other types of powder compression. This is an advantage as a higher temperature may cause decomposition or transformation of the constituting material. The produced body may also be after processed in some other way, such as HIP (Hot Isostatic Pressing).

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Further, the body produced may be a green body and the method may also comprise a further step of sintering the green body. The green body of the invention gives a coherent integral body even without use of any additives. Thus, the green body may be stored and handled and also worked, for instance polished or cut. It may also be possible to use the green body as a finished product, without any intervening sintering. This is the case when the body is a bone implant or replacement where the implant is to be resorbed in the bone.

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The metal is chosen from the group comprising light metal or alloy, ferrous based alloy, non ferrous based alloy and high melting metal or hard alloy. The metal may be chosen from the group including aluminium, titanium and alloys containing at least one of those, while an iron based alloy is chosen from a group including

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stainless steel, martensitic steel, low wrought steel and tool steel, and a high melting metal or hard alloy may be selected from the group comprising Co, Cr, Mo and Ni as well as alloys containing at least one of those. Preferred alloys for medical implants could be TiAlV and CoCrMo. A preferred alloy of CoCrMo is

- 5 Co₂₈Cr₆Mo (28 weight percent Cr, 6 weight percent Mo and the balance Co) and a preferred alloy of TiAlV is Ti₆Al₄V (6 weight percent Al, 4 weight percent V and the balance Ti).

- 10 The compression strokes need to emit a total energy corresponding to at least 100 Nm in a cylindrical tool having a striking area of 7 cm² for light metals. The same values for ferrous based metals is 100 Nm and for high melting and hard alloys is 100 Nm. The compression strokes need to emit an energy per mass corresponding to at least 5 Nm/g in a cylindrical tool having a striking area of 7 cm² for metals.

- 15 It has been shown earlier that better results have been obtained with particles having irregular particle morphology. The particle size distribution should probably be wide. Small particles could fill up the empty space between big particles.

- 20 The metal material may comprise a lubricant and/or a sintering aid. A lubricant may be useful to mix with the material. Sometimes the material needs a lubricant in the mould, in order to easily remove the body. In certain cases this could be a choice if a lubricant is used in the material, since this also makes it easier to remove the body from the mould.

- 25 A lubricant cools, takes up space and lubricates the material particles. This is both negative and positive.

Interior lubrication is good, because the particles will then slip in place more easily and thereby compact the body to a higher degree. It is good for pure compaction.

- 30 Interior lubrication decreases the friction between the particles, thereby emitting less energy, and the result is less inter-particle melting. It is not good for

compression to achieve a high density, and the lubricant must be removed for example with sintering.

Exterior lubrication increases the amount of energy delivered to the material and thereby indirectly diminishes the load on the tool. The result is more vibrations in the material, increased energy and a greater degree of inter-particular melting. Less material sticks to the mould and the body is easier to extrude. It is good for both compaction and compression.

An example of a lubricant is Acrawax C, but other conventional lubricants may be used. If the material will be used in a medical body, the lubricant need to be medical acceptable, or it should be removed in some way during the process.

Polishing and cleaning of the tool may be avoided if the tool is lubricated and if the powder is preheated.

A sintering aid may also be included in the material. The sintering aid may be useful in a later processing step, such as a sintering step. However, the sintering aid is in some cases not so useful during the method embodiment, which does not include a sintering step. The sintering aid may be boric acid or Cu-Mg, or some other conventional sintering aid. It should, as the lubricant, also be medical acceptable or removed, if used in a medical body.

In some cases, it may be useful to use both a lubricant and a sintering aid. This depends on the process used, the material used and the intended use of the body which is produced.

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In some cases it may be necessary to use a lubricant in the mould in order to remove the body easily. It is also possible to use a coating in the mould. The coating may be made of for example TiNAl or Balinit Hardlube. If the tool has an optimal coating no material will stick to the tool parts and consume part of the delivered energy, which increase the energy delivered to the powder. No time-consuming lubricating would be necessary in cases where it is difficult to remove the formed body.

In Example 4 are several external lubricants used. It is shown that grease and grease containing graphite showed better results than for example oils.

- 5 A very dense material, and depending on the material, a hard material will be achieved, when the metal material is produced by coalescence. The surface of the material will be very smooth, which is important in several applications.

- If several strokes are used, they may be executed continually or various intervals
10 may be inserted between the strokes, thereby offering wide variation with regard to the strokes.

- For example, one to about six strokes may be used. The energy level could be the same for all strokes, the energy could be increasing or decreasing. Stroke series may
15 start with at least two strokes with the same level and the last stroke has the double energy. The opposite could also be used. A study of different type of strokes in consecutive order is performed in one Example.

- The highest density is obtained by delivering a total energy with one stroke. If the
20 total energy instead is delivered by several strokes a lower relative density is obtained, but the tool is saved. A multi-stroke can therefore be used for applications where a maximum relative density is not necessary.

- Through a series of quick impacts a material body is supplied continually with
25 kinetic energy which contributes to keep the back and forth going wave alive. This supports generation of further deformation of the material at the same time as a new impact generates a further plastic, permanent deformation of the material.

- According to another embodiment of the invention, the impulse, with which the
30 striking unit hits the material body, decreases for each stroke in a series of strokes. Preferably the difference is large between the first and second stroke. It will also be

easier to achieve a second stroke with smaller impulse than the first impulse during such a short period (preferably approximately 1 ms), for example by an effective reduction of the rebounding blow. It is however possible to apply a larger impulse than the first or preceding stroke, if required.

5

According to the invention, many variants of impacting are possible to use. It is not necessary to use the counteracting of the striking unit in order to use a smaller impulse in the following strokes. Other variations may be used, for example where the impulse is increasing in following strokes, or only one stroke with a high or low impact. Several different series of impacts may be used, with different time intervals between the impacts.

10

A metal body produced by the method of the invention, may be used in medical devices, such as implants or medical instruments, for example surgical knives and diagnostic equipment. Such implants may be for examples skeletal or tooth prostheses.

15

According to an embodiment of the invention, the material is medically acceptable. Such materials are for example suitable metals, such as titanium, Ti6Al4V, stainless steel and Co28Cr6Mo.

20

A material to be used in implants needs to be biocompatible and haemocompatible as well as mechanically durable, such as titanium or other suitable metals mentioned above.

25

Other metals or alloys which may be used according to the invention are NiTi, Zr_xTi_y and CoCrMo. Other examples are, ferrous group metals, rare-earth metals and platinum group metals.

30

The body produced by the process of the present invention may also be a non medical product such as ball bearings, cutting tools, wearing surfaces, electrical

components, for instance wafers to be used in electrical circuits such as printed circuits. When producing a wafer the material body may contain small amounts of doping additives.

- 5 Here follows several applications for some of the materials. Stainless steel: hip ball, components that need to be resistant to corrosion. Tool steel: drills, hammers, screw drivers and mortise chisel. Aluminium alloy: in cars to decrease weight, many applications due to low density, high resistant to corrosion, high conductivity, high strength and good workability. Titanium: implant applications, such as plates,
10 screws and reconstructive joint prostheses. Ti6Al4V: orthopaedic implants, e.g. femoral portion of hip prostheses. Nickel alloy: humid environment due to resistance to corrosion, high temperature where the creep strength still is high, resistor element and hot plates. Co28Cr6Mo: orthopaedic implants related to joint deceases. The invention thus has a big application area for producing products according to the
15 invention.

When the material inserted in the mould is exposed to the coalescence, a hard, smooth and dense surface is achieved on the body formed. This is an important feature of the body. A hard surface gives the body excellent mechanical properties
20 such as high abrasion resistance and scratch resistance. The smooth and dense surface makes the material resistant to for example corrosion. The less pores, the larger strength is obtained in the product. This refers to both open pores and the total amount of pores. In conventional methods, a goal is to reduce the amount of open pores, since open pores are not possible to get reduced by sintering.

25

It is important to admix powder mixtures until they are as homogeneous as possible in order to obtain a body having optimum properties.

A coating may also be manufactured according to the method of the invention. One
30 metal coating may for example be formed on a surface of a metallic element of another metal or some other material. When manufacturing a coated element, the

element is placed in the mould and may be fixed therein in a conventional way. The coating material is inserted in the mould around the element to be coated, by for example gas-atomizing, and thereafter the coating is formed by coalescence. The element to be coated may be any material formed according to this application, or it
5 may be any conventionally formed element. Such a coating may be very advantageously, since the coating can give the element specific properties.

A coating may also be applied on a body produced in accordance with the invention in a conventional way, such as by dip coating and spray coating.

10

It is also possible to first compress a material in a first mould by at least one stroke. Thereafter the material may be moved to another, larger mould and a further metal material be inserted in the mould, which material is thereafter compressed on top of or on the sides of the first compressed material, by at least one stroke. Many
15 different combinations are possible, in the choice of the energy of the strokes and in the choice of materials.

The invention also concerns the product obtained by the methods described above.

20 The method according to the invention has several advantages compared to pressing. Pressing methods comprise a first step of forming a green body from a powder containing sintering aids. This green body will be sintered in a second step, wherein the sintering aids are burned out or may be burned out in a further step. The pressing methods also require a final working of the body produced, since the
25 surface need to be mechanically worked. According to the method of the invention, it is possible to produce the body in one step or two steps and no mechanical working of the surface of the body is needed.

When producing a prosthesis according to a conventional process a rod of the
30 material to be used in the prosthesis is cut, the obtained rod piece is melted and forced into a mould sintered. Thereafter follows working steps including polishing.

The process is both time and energy consuming and may comprise a loss of 20 to 50 % of the starting material. Thus, the present process where the prosthesis may be made in one step is both material and time saving. Further, the powder need not be prepared in the same way as in conventional processes.

5

By the use of the present process it is possible to produce large bodies in one piece. In presently used processes involving casting it is often necessary to produce the intended body in several pieces to be joined together before use. The pieces may for example be joined using screws or adhesives or a combination thereof.

10

A further advantage is that the method of the invention may be used on powder carrying a charge repelling the particles without treating the powder to neutralize the charge. The process may be performed independent of the electrical charges or surface tensions of the powder particles. However, this does not exclude a possible use of a further powder or additive carrying an opposite charge. By the use of the present method it is possible to control the surface tension of the body produced. In some instances a low surface tension may be desired, such as for a wearing surface requiring a liquid film, in other instances a high surface tension is desired.

15

20 Here follow some Examples to illustrate the invention.

EXAMPLES

Nine metals were examined: aluminium alloy, stainless steel, martensitic steel, low wrought steel, tool steel, an alloy of Co28Cr6Mo, an alloy of Ti6Al4V, titanium and nickel alloy.

25

Example 1, energy and additive study, heat study

The material was tested with and without additives. The energy levels of the strokes were compared. Within each metal type four batches were tested, except for two of them (titanium and titanium alloy, no sintering aid is necessary when titanium is

30

present). "Batch 1" is pure powder, "batch 2" is powder with lubricant (Acrawax C), "batch 3" is powder with sintering aid (boric acid or Cu-Mg) and "batch 4" is powder with lubricant (Acrawax C) and sintering aid (boric acid or Cu-Mg).

However, the four batches are only shown for stainless steel in the figures. For the other metals are only the graphs for batch 1 and batch 2 shown.

Preparation of powder

The preparation was the same for all the metals, if nothing else is said.

The pure powder, batch 1, was initially dry-mixed for 10 minutes to obtain a homogeneous particle size distribution in the powder.

The powder with lubricant, batch 2, was initially dry-mixed with 1 wt % Acrawax C for 15 minutes to obtain a homogeneous particle size distribution in the powder.

The powder, batch 3, of aluminium alloy already contained sintering aids (Cu-Mg) and was therefore only mixed for 10 minutes to obtain a homogeneous particle size distribution in the powder.

For all the other metal types, batch 3, methanol was mixed with boric acid and stirred with the powder. The mix was dried out and thereafter put in 310 °C for 30 minutes to let desired reactions between the metal and the boric acid occur. Thereafter the powder was left to cool down before it was dry-mixed for 15 minutes to obtain a homogeneous particle size distribution in the powder.

The Al alloy powder, batch 4, already contained sintering aids (Cu-Mg) as well and therefore was the powder only mixed together with 1 wt% Acrawax C for 15 minutes to obtain a homogeneous particle size distribution in the powder and an homogenous mixture between powder and lubricant.

For all the other metal types, batch 4, methanol was mixed with boric acid and stirred with the powder. The mix was dried out and thereafter put in 310 °C for 30

minutes to let desired reactions between the metal and the boric acid occur. Then the powder was left to cool down before it was dry-mixed with 1 wt% Acrawax C for 15 minutes to obtain a homogeneous particle size distribution in the powder.

5 Description

The first sample in all four batches included in the energy and additive studies was pre-compacted one time with a 117680 N axial load. The following samples were first pre-compacted one time, and thereafter compressed with one impact stroke. The impact energy in this series was between 150 and 4050 Nm (some batches stopped at a lower impact energy), and each impact energy step interval was 150 Nm or 300 Nm.

After each sample had been manufactured, all tool parts were dismantled and the sample was released. The diameter and the thickness were measured with electronic micrometers, which rendered the volume of the body. Thereafter, the weight was established with a digital scale. All input values from micrometers and scale were recorded automatically and stored in separate documents for each batch. Out of these results, the density 1 was obtained by taking the weight divided by the volume.

20

To be able to continue with the next sample, the tool sometimes needed to be cleaned, either or only with acetone or polishing the tool surfaces with an emery cloth to get rid of the material rests on the tool.

25 To easier establish the state of a manufactured sample three visibility indexes are used. Visibility index 1 corresponds to a powder sample, visibility index 2 corresponds to a brittle sample and visibility index 3 corresponds to a solid sample.

The theoretical density is either taken from the manufacturer or calculated by taking all included materials weighed depending on the percentage of the specific material.

30

The relative density is obtained by taking the obtained density for each sample divided by the theoretical density.

Density 2, measured with the buoyancy method, was performed with all samples.

- 5 Each sample was measured three times and with that three densities were obtained. Out of these densities the median density was taken and used in the figures. To begin with, all samples were dried out in an oven, in 110 °C for 3 hours, to enable the included water to evaporate. After the samples had cooled down, the dry weight of the samples was determined (m_0). That followed by a water penetration process
- 10 where the samples were kept in vacuum and water, where two drops wetting agent was added into the water. The vacuum forced out the eventual air and the pores were filled with water instead. After an hour the weight of the samples, both in water (m_2) and in air (m_1), was measured. With m_0 , m_1 , m_2 and the temperature of the water, the density 2 was determined.

15

- The volume of open pores and closed pores was also measured. The open pores were filled with water and the volume of this water could be calculated. The volume % of the total pores is the difference between 100 % and the relative density and hence the closed pores may be calculated as the difference between the vol % of the
- 20 total pores and the open pores.

Sample dimensions

- The dimensions of the manufactured sample in these tests is a disc with a diameter of ~30.0 mm and a height between 5-10 mm. The height depends on the obtained
- 25 relative density. If a relative density of 100 % should be obtained the thickness is 5.00 mm for all metal types, since the masses of every metal has been chosen to give the same volume.

- In the moulding die (part of the tool) a hole with a diameter of 30.00 mm is drilled.
- 30 The height is 60 mm. Two stamps are used (also parts of the tool). The lower stamp is placed in the lower part of the moulding die. Powder is filled in the cavity that is

created between the moulding die and the lower stamp. Thereafter is the impact stamp placed in the upper part of the moulding die and strokes are ready to be performed.

- 5 The theoretical density of batch 2, 3 and 4 in the energy and additive studies is determined to the same as for pure powder because the real theoretical density is extremely difficult to calculate when additives have been added.

10 Relative density vs total impact energy and relative density vs energy per mass, is chosen for all metals. However, for stainless steel 316L, relative density vs impact velocity is shown in a Figure. The four batches will be plotted for stainless steel, but only two batches for the other metals, since the differences between the curves are similar. Density 2 is used in most cases, except when it was not possible to measure density 2.

15

In some cases an external lubricant, Acrawax C, was used to make it easier to remove the samples. Sometimes the tool needed to be cleaned to remove material, which was stuck during the process.

20 Results

Table 1 and 2 shows the properties for the metal types. Table 1 includes the non-ferrous based metals and Table 2 includes the ferrous based metal. Titanium is manufactured at Good Fellows and they could not tell the particle distribution.

TABLE 1

Properties	Ti-6Al-4V	Titanium	Co-28Cr-6Mo	Al-alloy	Ni-alloy
1. Particle size (micron)	< 150	<150	<150	<150	<150
2. Particle distribution (micron)			2 wt% > 150 balance < 150	0.1 wt% > 250 3 wt% > 200 5 wt% > 160 5-20 wt% > 100 20-35 wt% > 63 10-25 wt% > 45 35 50 wt% < 45	6.57 wt% > 125 50.80 wt% > 106 24.25 wt% > 100 12.26 wt% > 90 6.12 wt% < 90
3. Particle morphology	Irregular	Irregular	Irregular	Irregular	Irregular
4. Powder production	-	Hydrated	Water atomised	Water atomised	Water atomised
5. Crystal structure	Al stabilises HCP V stabilises BCC	HCP	85 % alpha phase 15 % carbides	FCC	FCC
6. Theoretical density (g/cm ³)	4.42	4.5	8.5	2.66	8.38
7. Apparent density (g/cm ³)	1.77	1.80	3.4	1.22	2.59
8. Melt temperature (°C)	1600-1650	1660	1350-1450	658	1645
9. Sintering temperature (°C)	1260	1000	1200	600	1315
10. Hardness (HV)	-	60	460-830	50-100	80-200

TABLE 2

Properties	Stainless steel 316L	Low wrought steel	Martensitic steel	Tool steel
1. Particle size (micron)	< 150	<150	<150	<150
2. Particle distribution (micron)	0.60 wt% > 150 42.70 % < 45	3.2 wt% > 150 79.5 wt% < 150	1.06 wt% > 150 4.32 wt% > 125 12.03 wt% > 106 23.59 wt% > 75 19.26 wt% > 53 9.04 wt% > 45 30.70 wt% < 45	0.4 wt% 150-180 24.48 wt% 106-150 26.68 wt% 75-106 28.67 wt% 45-75 19.77 wt% < 45
3. Particle morphology	Irregular	Irregular	Irregular	Irregular
4. Powder production	Water atomised	Water atomised	Water atomised	Water atomised
5. Crystal structure	FCC	BCC < 900 °C FCC > 900 °C	FCC	BCC < 910 °C FCC > 910 °C
6. Theoretical density (g/cm ³)	7.90	7.75	7.73	7.75
7. Apparent density (g/cm ³)	2.64	2.87	3.37	2.55
8. Melt temperature (°C)	1427	1540	1427	1350-1450
9. Sintering temperature (°C)	1315	1230	1230	1315
10. Hardness (HV)	160-190	130-280	180-330	207-241

Stainless steel 316LHD (Höganäs)

Sample weight 28 g. Number of samples made, batch 1:28, batch 2:11, batch 3:21,
5 batch 4:11. 150 Nm step interval for batch 1, 300 Nm for batch 2, 3 and 4.

Figure 2 shows the relative density as a function of total impact energy. All samples
were solid except for the pre-compacting samples from the batch containing
lubricant and the batch containing sintering aid. After the pre-compacting of the
batch with only sintering aid, there was only powder obtained. With the batch with
10 only lubricant added, a brittle sample was obtained.

When the stroke with lowest total energy, 300 Nm, is performed a solid sample was
obtained at all batches (150 Nm for pure batch).

15 The highest obtained relative density for the pure powder, 95.1 % is obtained at
3450 Nm, for the batch containing lubricant 90.5 % is obtained at 2550 Nm, for the
batch containing sintering aid 93.3 % is obtained at 3300 Nm and for the batch
containing both lubricant and sintering aid 89.6 % is obtained at 3150 Nm.

20 Figure 3 shows the relative density as a function of impact energy per mass. The
highest relative density, 95.0 % is obtained for 123 Nm/g for the pure powder. The
highest relative density obtained was 91.4 % for 91 Nm/g for the batch containing
lubricant. The highest obtained relative density was 85.6 % for 80.2 Nm/g for the
batch containing only sintering aid. The highest reached density, 89.6 % is obtained
25 for 113 Nm/g for the bath containing both lubricant and sintering aid.

Figure 4 shows the relative density as a function of impact velocity of the stroke
unit.

30 The difference in density between the pure batch and the batch containing lubricant
may be caused by the volume of the lubricant in the body produced.

The sintering aid does not react as in conventional sintering, only in some extent or not at all. It is shown that bodies are produced with a little lower relative density compared to the pure powder.

5

For the following metals are only batch 1 and batch 2 shown in the graphs.

Martensitic steel, (410 L, Höganäs)

Sample weight 27.1 g. Number of samples made, batch 1:21, batch 2:11. Impact
10 energy step interval 150 Nm for batch 1 and 300 Nm for batch 2.

Figure 5 shows relative density as a function of total impact energy. The pure batch was solid after pre-compacting (visibility index 3). For the batch containing lubricant, the first body sample was obtained at an impact stroke energy of 300 Nm. The pre-compacted sample of batch 2 had visibility index 1. The highest density
15 was reached for the pure powder with a density of 96.0 % at 2250 Nm and 92.5% at 3000 Nm for batch 2.

Figure 6 shows the relative density as a function of impact energy per mass.

20 Low wrought steel, (Astaloy CrM, Höganäs)

Sample weight 27.4 g. Number of samples, batch 1: 29, batch 2:11. Impact energy step interval: batch 1:150 Nm, batch 2: 300 Nm. The material was soft annealed. Figure 7 shows the relative density as a function of total impact energy. The sample of the batch with no lubricant additive was solid body at pre-compacting (visibility
25 index 3). For the batch containing lubricant additive the first solid body sample was obtained at an impact stroke energy of 300 Nm. The pre-compacted sample in the batch containing lubrication additive was brittle and fell apart when touched (visibility index 2). Maximum relative density 97.6 % for batch 1 was obtained at 3000 Nm, and 93.1 % at 2400 Nm for batch 2.

30

Figure 8 shows the relative density as a function of impact energy per mass.

Tool steel, (H13, Powdrex (Höganäs, Great Britain))

Sample weight 27.4 g. Impact energy step interval 150 Nm for batch 1 and 300 Nm for batch 2. The material was annealed.

- 5 Figure 9 shows relative density as a function of total impact energy. The samples were solid after pre-compacting. Maximum relative density obtained is 95.6 % at 2700 Nm.

Figure 10 shows relative density as a function of impact energy per mass.

10 Aluminium alloy Al12Si (12 weight percent Si and the balance Al), (Eckart-granules)

Sample weight 9.4 g. Number of samples, batch 1:21, batch 2: 11. Impact energy step interval 150 Nm for batch 1 and 300 Nm for batch 2.

- Figure 11 shows relative density as a function of total impact energy. A solid
15 sample was obtained with the pure powder batch after the pre-compacting process. With the batch with only lubricant added a brittle sample was obtained (visibility index 2).

- When the first stroke, 300 Nm, is performed a solid sample was obtained at all
20 batches (150 Nm for batch 1). The batch containing only lubricant reaches the highest density, 98.2 % at 3000 Nm. The highest density for batch 1 is 97.1 % at 3750 Nm.

Figure 12 shows the relative density as a function of impact energy per mass.

- 25 Aluminium alloy has an oxide layer on the surface, which is a disadvantage during the process, which might lead to that higher energy levels need to be used.

Titanium, with purity of 99.5 % (Goodfellow)

- Sample weight 16 g. Number of samples, batch 1: 25, batch 2:11. Impact energy
30 step interval: batch 1: 150 Nm, batch 2: 300 Nm.

Figure 13 shows relative density as a function of total impact energy. A solid sample (visibility index 3) was obtained with the pure powder batch after the pre-compacting process. After the pre-compacting of the batch with lubricant, Acrawax C, there was a brittle sample obtained (visibility index 2).

5

When the first stroke, 150 respectively 300 Nm, was performed a solid sample was obtained at both batches.

At a lower impact energy than 1050 Nm the relative density of the pure powder batch is lower than the batch where lubricant is added, but above 1050 Nm flattens the curve of the batch with lubricant out, but the pure powder batch still increases.

Maximum relative density obtained for batch 1 is 97.0 % and for batch 2 93.9 %.

15 Figure 14 shows relative density as a function of impact energy per mass.

Ti6Al4V (Sulzer)

Sample weight 16 g. Number of samples made, batch 1: 20, batch 2: 11. Impact energy step interval, batch 1: 150 Nm, batch 2: 150 Nm, 300 Nm.

20 Figure 15 shows relative density as a function of total impact energy. A solid sample (visibility index 3) was obtained with the pure powder batch after the pre-compacting process. After the pre-compacting of the batch with lubricant, Acrawax C, there was a brittle sample (visibility index 2) obtained.

25 When the first stroke of the pure powder batch, 150 Nm, and the 4th stroke of the batch with lubricant, 1200 Nm, were performed a solid sample was obtained. Thus, visibility index 2 is obtained for 300, 600 and 900 Nm for batch 2. Visibility index 2 was also obtained for 3000 Nm. The highest obtained relative density is 93.5 % at 2550 Nm for batch 1.

30

Figure 16 shows relative density as a function of impact energy per mass.

Nickel alloy (Hastelloy X, Höganäs)

Sample weight 23 g. Number of samples made, batch 1: 27, batch 2:11. Impact energy step interval, batch 1:150 Nm, batch 2: 300 Nm.

- 5 Figure 17 shows relative density as a function of total impact energy. A solid sample was obtained with the pure powder batch after the pre-compacting process. After the pre-compacting of batch 2 a powder sample was obtained (visibility index 1).
- 10 When the first stroke, 300 Nm, was performed visibility index 2 was obtained for batch 2 and visibility index 3 for 600-3000 Nm. Maximum relative density 91.8 % for batch 1 is obtained at 4170 Nm.

Figure 18 shows relative density as a function of impact energy per mass.

15

Co28Cr6Mo (Stellite, Höganäs)

Sample weight 30 g. Number of samples made, batch 1: 26, batch 2:11. Impact energy step interval, batch 1:150 Nm, batch 2: 300 Nm.

- Figure 19 shows relative density as a function of total impact energy. Almost all
- 20 samples were brittle and some of them also missed some parts of the sample. For the pure powder and the batch containing lubricant, there was not formed a material body (still powder) when the first stroke had been performed. The first solid body, visibility index 2, was obtained at 600 Nm for the two batches. Maximum relative density is 87.3 % for batch 1 at 3900 Nm and 83.3 % for batch 2 at 1800 Nm.

25

Figure 20 shows relative density as a function of impact energy per mass.

- Figure 21 shows relative density as a function of total impact energy for the non ferrous based metals and Figure 22 for the ferrous based metals. Aluminium alloy
- 30 shows the highest density, which can be expected, since it is a soft alloy and have a low melting point. Titanium show about the same relative density at higher impact

energies. For the ferrous based metals, low wrought steel shows the highest density at lower impact energies, while tool steel obtains about the same density at higher energy levels.

- 5 Internal lubricant enabled the possibility to avoid external lubricant in the most cases. For metal batches with material added, a lower relative density was in general obtained. This may depend on that calculations of relative density, when material is added, is difficult to perform. It may also depend on that it is more difficult to get a high relative density when the material contains an additive. The difference of
10 visibility index after e.g. pre-compacting showed that samples, where either lubricant or sintering aid are added, obtained a lower relative density than the batches 1, pure powder. The boric acid is solved in methanol before it is stirred with the powder, and therefore the boric acid is applied as a coating around each particle. That could make it more difficult to obtain the inter-particle melting between the
15 powder particles. Internal lubricant, Acrawax C, seems to take space in the powder. The powder is not solved and with that not coated around each particle, but when the particles fuse the Acrawax C particles could disturb the inter-particle melting. All additives must very often be removed during post-processing, such as sintering. The result shows, however, that the material containing additives are possible to
20 compress to solid bodies. There is a trend that the harder metal, e.g. Co28Cr6Mo, the more difficult to compact and reach a solid sample with high relative density. Soft annealed powder is easier to compact, since the hardness is decreased.

Figure 23 shows relative density as a function of impact energy per mass for the
25 non ferrous based metals and Figure 24 for the ferrous based metals. At less than 75 Nm/g, in figure 23, the highest relative density was obtained with aluminium alloy. Thereafter, consecutively titanium, nickel alloy and then Co-28Cr-6Mo and Ti-6Al-4V. But at an impact energy per mass higher than 75 Nm/g, the obtained relative density for each material type developed differently. Now the titanium received the
30 highest relative density of 97.0 %. Thereafter, consecutively aluminium alloy at 97.0 % as well but received at a higher impact energy per mass than for titanium.

Thereafter 95.0 % was obtained for Ti-6Al-4V, nickel alloy 91.8 % and Co-28Cr-6Mo 87.3 %.

In Figure 24, low wrought steel obtained the highest relative density, 97.6 %, among the ferrous based material types. Thereafter consecutively martensitic steel, 97.0 %, stainless steel 316L, 95.5 % and tool steel, 95.0 %.

It is important that the sample does not contain any open pores, because only closed pores can be reduced by sintering. The strength of the material increases with decreasing amount of total and/or open pores. Equal or better than 3 volume % of closed pores and 0 volume % of open pores can be obtained with this method, which is better compared to conventional powder processing before sintering. Figure 25 shows total porosity as a function of amount of pores for a aluminum alloy. Three curves compare the amount of total-, close- and open pores in the tested samples. The samples containing the greatest amount of pores are compressed with the lowest energy level.

The curve for the open pores decreases from 18 vol% to 0 vol %. The curve for the closed pores decreases from ~12 vol % to ~2.7 vol%. The sample with 2.7 vol % closed pores and 0 vol % open pores has a relative density of 97.1 % and is compressed with an impact energy of 2100 Nm.

The result is a confirmation that this method can achieve similar result in porosity compared with conventional powder processing.

Heat study

Co-28Cr-6Mo was tested in the heat study. The Co-28Cr-6Mo powder has been difficult to compress properly and to high densities.

The goal with the heat testing was to evaluate how a pre-heating of different materials affect the compressing process and density of the sample.

The powder was first pre-heated to 210 °C for 2 hours, to obtain an even temperature in the powder. Then the powder was poured into a room tempered mould and the temperature of the powder was measured during the pouring into the
5 mould. As fast as possible the tool was mounted and the powder pre-compacted with 117680 N axial load and struck between 300 to 3000 Nm. The result was then compared with the non pre-heated test series.

The density for silicone nitride, Co-23Cr-6Mo, was measured with the buoyancy
10 method, was performed with all samples. Each sample was measured three times and with that three densities were obtained. Out of these densities the median density was taken and used in the figures. The density was measured as above.

Figure 44 and 45 show relative density as a function of total impact energy and
15 impact energy per mass for Co28Cr6Mo. The powder had a temperature between 150-180 °C before compacting.

The powder had a temperature between 170 -190 °C before compacting. The sample weight was 30.0 g. Number of samples 26 for non preheated, 8 for pre-
20 heated. The two curves follow each other. The difference between the pre-heated and non pre-heated powder was that the preheated samples earlier reached visibility index 3, already at 300 Nm of impact energy. The sample for the pre-heated test was less brittle and had a finer outer surface, which looked polished. Compared with the samples from the non-preheated test, the first solid body was obtained at
25 ~1200 Nm. Both pre-compacted samples had visibility index 1.

Preheating had a positive effect on the condition of the samples after the removal. Co28Cr6Mo looked less brittle and reached a better visibility index for less impact energy. There was less material coating in the tool after compressing a pre-heated
30 Co28Cr6Mo powder.

Energy study

An energy study was performed with stainless steel using multi stroke sequence where each stroke had an impact energy of either 1200 or 2400. The samples was then struck between 1 to 5 strokes with a time interval 0.4 or 0.8 s between the strokes.

Figure 46 shows the curve for 2400 Nm per stroke with different time intervals. The curves are parallel so the time interval change between 0.4 and 0.8 s has not affected the result. They reaches the highest density, 96.6 % at 5 strokes which in this case corresponds to 12000 Nm

Example 2, parameter studies

The parameter studies include weight study, velocity study, time interval study and a number of stroke study. These studies were only done for stainless steel 316L.

For the parameter studies pure powder was used, which means that it was prepared by dry-mixing the powder for 10 minutes.

Description

In the weight study, the impact energy interval was from 300 to 3000 Nm with a 300 Nm impact step interval. The only parameter that was varied was the weight of the sample. It rendered different impact energies per mass.

In the velocity study, the impact energy interval was from 300 to 3000 Nm with a 300 Nm impact step interval. But here different stroke units (weight difference) were used to obtain different maximum impact velocities.

In the time interval study and the number of strokes study, the total impact energy level was either 1200 Nm or 2400 Nm. Sequences of two to six strokes were investigated. Prior to the impact stroke sequence the specimens were pre-compacted using static axial pressure of 117680 N. The time interval between the strokes in a

sequence was 0.4 or 0.8 s. In the number of strokes study, five different stroke profile sequences were investigated.

5 The same dismounting of the samples and measuring the density of the samples was done as in Example 1.

Weight study

10 Stainless steel powder was compressed using the HYP 35-18 impact machine for three series of three different sample weights; 7, 14, 28 and 56 g. The 28 g sample series is the series described in Example 1 for stainless steel. The 7 g, 14 g and the 56 g samples corresponds to a fourth, a half and the double the weight of the 28 g sample. The series were performed with a single stroke going from an minimum impact level to a maximum with increasing energy step intervals. The maximum, minimum and step energies are compiled in table 1. All samples were pre-
15 compacted before the impact stroke.

In figure 26 and 27 the four test series are plotted for relative density as a function of impact energy per mass and total impact energy. Since the highest total impact energy is constant (max 3000 Nm) the half weight and the fourth weight series will
20 reach higher energy levels per mass. The maximum relative densities reached are 94.4, 94.3, 95.6 and 94.5 %, respectively. The results show that a higher density is obtained when the sample mass is increased for a given energy level per mass. The results show that this method demands less energy per mass for a body with a bigger mass compared to a body with a smaller mass, to reach the same density. A
25 larger body would faster obtain the maximum density, which is seen in Figure 26.

The result shows that the method is dependent on the energy per mass for essentially low densities obtained. When essentially higher densities are obtained, the method is not depending on the energy per mass, but the total energy is
30 independent on the mass. This is described earlier in the description.

Velocity study

Stainless steel powder was compressed using the HYP 35-18, HYP 36-60 and a high velocity impact machine. For the high velocity impact machine the impact ram weight could be changed and three different masses were used; 7.5 , 14.0 and 20.6 kg. The impact ram weight for the HYP 35-60 is 1200 kg and for the 35-18 350 kg. The sample weight was 28 g. All samples were performed with a single stroke. The series were performed for energies increasing in steps of 300 Nm ranging from pre-compressing to a maximum of 3000 Nm. All samples were also pre-compacted before the impact stroke. The pre-compacting force for the HYP 35-18 was 135 kN, for the HYP 35-60 it was 260 kN and for the high velocity machine 18 kN. The highest impact velocity 28.3 m/s is obtained with the 7 kg impact ram and the slowest impact velocity, 2.2 m/s, is obtained with the impact ram mass 1200 kg, HYP 35-60 machine, for the maximum energy level of 3000 Nm.

In figure 28 the five test series are plotted for relative density as a function of impact energy per mass. Figure 29 shows the relative density as a function of total impact energy and figure 30 shows the relative density as a function of impact velocity. The difference between the maximum densities for the five series are up to 10 percent. The results indicates that a higher increase in relative density is obtained when the impact ram mass is increased or equivalent a decreased impact velocity. The effect is decreased as the energy is increased. The relative density at pre-compacting is to a great extent dependent on the static pressure. The pre-compacted samples for the 7.5, 14.0 and 20.6 kg impact rams were not transformed to solid bodies, but instead powder and described as visibility index 1. Figure 31 shows the relative density as a function of impact velocity at a total impact energy level of 1500, 2100 and 3000 Nm. The figure shows that the relative density increases as the impact velocity decreases.

Time interval study and number of stroke study

The specimens of this study are manufactured using a multi stroke sequence with a total impact energy level of either 1200 Nm of 2400 Nm. Sequences of two to six

strokes were investigated with the same energy for each stroke. The material used is pure stainless steel powder 316 L. Prior to the impact stroke sequence the specimen were pre-compacted using static axial pressure of 117680 Nm. The time interval between the strokes in a sequence were 0.4 or 0.8 s. Five different stroke profile sequences were investigated, "Low-High", "High-Low", "Stair case up", "Stair case down", and "Level". In the "Low-High" sequence, the final stroke in the sequence is twice the energy level of the sum of the equi-level of the former strokes. Hence, the "High-Low" sequence is the mirror sequence with an initial high impact energy stroke. The stair case up and down sequences are stepwise increasing or decreasing energy levels in the same sequence. All increases or decreases of steps in a sequence are the same. The "Level" sequence is performed with each stroke at the same impact energy level. The sample weight was 28.0 g.

Figure 32 and Figure 33 show the level strokes sequences of 1200 and 2400 Nm correspondingly. Each energy level is performed for both the time between the strokes of $t_1 = 0.4$ s and $t_2 = 0.8$ s. Studying the Figure 32 an indication of decreasing density could be seen for the $t = 0.4$ s sequence as the total energy is divided on a larger number of strokes. The $t = 0.8$ s sequence does not indicate on any direction of change in density as the number of impact strokes increases. For the 2400 Nm energy level, Figure 32, both the $t = 0.4$ s and the $t = 0.8$ s interval sequences indicates on a decreasing density with number of strokes. However, the indication is more pronounced for the $t = 0.8$ s sequence. Generally for the two energy levels, by studying the mean value of the sequences, is that the $t = 0.8$ s sequence gives a higher density than for the $t = 0.4$ s sequence. For the 1200 Nm series the $t = 0.4$ s has an average of 89.8 and the $t = 0.8$ s sequence 90.4 % relative density. Corresponding values for the 2400 Nm series are 92.4 and 92.8 % relative density.

Figure 34 shows a stroke profile for energy level 1200 Nm and with $t = 0.4$ s. The "Stair case" sequences were limited to two, three and four stroke sequences due to the limitations of the HYP machine programme of four individual stroke settings.

Generally for the first three strokes the density increases. For the fifth and sixth stroke sequences the density indicates to decrease. The latter could however not be concluded for the stair case sequences. The "Stair case up" and "Low-High" sequences indicates a higher density than their counterparts "Stair case down" and "High-Low". The same indication could also be seen for 1200 Nm $t = 0.8$ s sequences, which is not shown. Generally little difference could be seen for the different stroke profiles sequences for the same total impact energy. Maximum density was obtained for in the 2400 Nm sequence of four strokes with a "Low-High" profile with the relative density of 94.7 %.

Example 3, compacting study

Stainless steel was used in this study. The powder was initially dry-mixed for 10 minutes to obtain a homogeneous particle size distribution in the powder.

Five different compressing tests were performed. All series were struck from 300 Nm to 3000 Nm with an energy interval of 300 Nm between each test.

The first series was a double pre-compacting series. All samples were pre-compacted two times with 117680 N axial load with approximately 5-10 seconds between them.

The second series was a triple pre-compacting series. All samples were pre-compacted three times with 117680 N axial load with approximately 5-10 seconds between them.

In the third series the samples were first pre-compacted, struck and after compacted with the 115720 N axial load directly after the stroke, which means that the striking unit did not return to its initial position after it had struck the powder. The striking unit was instead kept for 5 seconds in its lowest stroke position and pressed the compacted sample.

In the fourth series were the samples first pre-compacted, struck and after compacted with a 115720 N axial load after the stroke, but with a delay of 10 seconds, which meant that the striking unit returned to its initial position after the stroke and then after compacted the sample with 117680 N axial load.

5

In the fifth series the samples were double pre-compacted with 117680 N axial load, struck and after compacted with a 115720 N axial load directly after the stroke.

10 The density was measured according to the methods used in Example 1 and 2.

Figure 35 shows relative density as a function of total impact energy, which shows all the different compacting series compared with each other and Figure 36 show relative density as a function of impact energy per mass. The x axis starts at 600 Nm
15 and 20 Nm/g respectively and the y axis at 83 % in both figures.

The highest pre-compacting result, 59.5 %, was obtained for the triple pre-compacting and it was 1.2 % higher compared with the single pre-compacted sample. All the pre-compacted samples had visibility index 2 after removal from the
20 tool. At 300 Nm (11 Nm/g, 1.3 m/s) of impact energy the first body with visibility index 3 were obtained for all tests series, where the highest obtained relative density was 77.7 % obtained for the single pre-compacted and late after compacted sample.

The highest obtained relative density was 95.7 % for the single pre-compacting
25 series with a late after compacting obtained at 3000 Nm (109 Nm/g, 4.1m/s) and 95.3 % at 2400 Nm (86 Nm/g, 3.7) for the double pre-compacting plus direct after compacting.

This is 1.5 % higher relative density compared with the single pre-compacted
30 series.

The data obtained from this test is collected in Table 3.

TABLE 3

	Relative density 2 of pre-compacted sample (%)	Relative density 2 of first obtained body (%)	Maximum relative density 2 (%)	Impact energy at maximum relative density 2, (between 0-3000 Nm)
Single pre-compacting	58.5	71.8	94.2	2400
Double pre-compacting	59.5	77.3	94.7	2400
Triple pre-compacting	59.7	76.7	94.5	3000
Single + after compacting	58.5	77.2	95.1	2700
Single + late after compacting	59.2	77.7	95.7	3000
Double pre-compacting + after compacting	59.5	76.9	95.3	2400

- 5 All tests series showed the same indication: Several pre-compacting or after compacting increases the relative density. One reason is probably that a pre-compacting with a higher pressure can force out more air from the powder. The results showed that a double compacting gives a better result than a single compacting, which probably means that the total pressure that is needed to obtain
- 10 the best green density before the powder is struck is a double pre-compacting.

An after compacting effect the sample differently than a pre-compacting. What probably happens is that the transmitted energy, which increase the local temperature between the powder particles from the stroke is conserved for a longer

15 time and can effect the sample to consolidate for a longer period after the stroke. The theory that a material wave which arises in the material after a stroke, is supported by these results. Probably the "lifetime" for the material wave in the sample is increased and can effect the sample for a longer period and more particles can melt together.

20

In some curves, the relative density was not possible to measure and those points have been left out.

Figure 47 shows relative density as function of number of strokes. The samples

25 were struck with 1 to 21 strokes with a total impact energy of 3000 Nm and 4000

Nm. The two curves are compared in figure 47.

The highest reached relative density is 95.1 % for two strokes and a total impact energy of 4000 Nm. The 4000 Nm curve decreases regular ~11 % from 95.1 % to 84 % of relative density with increasing number of strokes. The 3000 Nm curve lies 2 % below the 4000 Nm curve which supports the trend. The relative density decreases from 93 % to 82 % which also is an 11 % decrease in density.

Example 4, lubricant test

Some lubricants were tested as external lubricants to use in the mould. The tests were performed with stainless steel 316L and with pure titanium. The main part of the tests were performed with pure titanium though that metal type did stick to the tool surfaces much more than ss 316L. The lubricants tested are Li-CaX grease with different amount graphite added, oils with different viscosity, Teflon spray and Teflon grease, grease with graphite added, grease with talc in different combinations, LiX grease with different amount boron nitride added and other types of greases and oils.

The lubricants used are the following:

- 3 to 9 wt% graphite mixed with chassis grease
- Cooking oil
- Motor oil
- MoS₂-grease
- Talc powder in pure form or 3-9 wt % mixed with chassis grease
- Teflon oil in spray form
- Glide way 220 (Lubricating oil)
- Chain way BioPine (Chain Saw oil)
- Grease way CaH (Lubricating grease)
- Li-stearate with grease (LiX complex)
- Boron nitride in pure form or 5 to 15 wt % mixed with grease (LiX complex)

Li-Ca stearate with grease (Li-CaX 90) in pure form or mixed with 5 to 15 wt % graphite

Ester based oil 180 viscosity

Ester based oil 650 viscosity

5 Ester based oil 1050 viscosity

Teflon grease

10 The external lubricants were applied with a paint brush on the lower stamp (side that is in contact with the powder and at the sides that are in contact with the moulding die), the moulding die and at the impact stamp (both on the side that is in contact with the powder and on the sides that are in contact with the moulding die). All to be enable an easier release of the stamps and the sample and avoid powder rests on the tool.

15

There will also be tested how different lubricants affect the obtained relative density. Several types of lubricants were tested where different parameters were varied. The amount of graphite, two types of graphite, the amount of boron nitride in grease and the viscosity are all tested to determine the behaviour of each parameter.

20

Both stainless steel 316L and titanium were initially dry-mixed for 10 minutes to obtain a homogeneous particle size distribution in the powder.

25 Each lubrication type was applied on the tool surfaces. The first sample in some batches were pre-compacted with 117680 N axial load and some not. The following samples (and in some batches the first sample) were initially pre-compacted and thereafter stricken with one impact stroke. The impact energy in these series were different depending on the amount of material lefts on the tool surfaces. Each test

30 started at 300 and increased with a 300 Nm impact step interval.

Between each sample, the tool needed to be cleaned, either or only with a rag, acetone or polishing the tool surfaces with an emery cloth to get rid of the material rests on the tool.

- 5 To easier establish the state the required cleaning of the tool, after a sample had been produced, six stickiness indexes were used. The description of each stickiness index is described in table 4.

TABLE 4

Stickiness index	Description
0	Wipe the tool surfaces with a dry rag
1	Wipe the tool surfaces with acetone
2	Polish with an emery cloth < 1 minute
3	Polish with an emery cloth 1-10 minutes
4	Polish with an emery cloth > 10 minutes
5	The tool needs to be removed to be able to polish the tool surfaces with either a polishing machine or by hand

10

The density was measured according to the methods described in Examples 1 and 2.

Li-CaX grease with different amount of graphite added

Figure 37 shows relative density as a function of total impact energy. A curve for

- 15 Acrawax C is used as a reference curve to the curves where Li-CaX grease with different amounts of graphite has been added. It is a reference curves for the other lubricants also. Table 5 includes the stickiness index for different impact energies.

TABLE 5

Total impact energy (Nm)	Stickiness index				
	Li-CaX	Li-CaX, 5 wt% graphite	Li-CaX, 10 wt% graphite	Li-CaX, 15 wt% graphite	Acrawax C
0	0	0	0	0	2
300	1	1	0	0	2
600	3	2	0	1	2
900		2	0	1	2
1200		2	0	4	3
1500		2	1		3
1800		4	3		3
2100					4
2400					4
2700					4

20

All samples had visibility index 3. The obtained relative densities of all batches were similar. The stickiness index for Li-CaX with 10 weight % graphite rendered stickiness index 0 to 1500 Nm, while the other batches rendered a higher stickiness index at much lower impact energy.

Oils with different viscosity

Figure 38 shows relative density as a function of total impact energy. With cooking oil as lubricant ~5 % lower relative density was obtained comparing with the other lubricants. There can not be determined what viscosity of the rest of the oils that obtains the highest relative density. For the oils with a viscosity of 650 and 1050 PaS the samples had visibility index 2. With cooking oil and oil with 180 PaS the samples had visibility index 3. Acrawax C rendered the highest relative density compared with all oils.

See table 6 for results of stickiness indexes of oils with different viscosity.

TABLE 6

Total impact energy (Nm)	Stickiness index				
	Cooking oil	Oil, 180 PaS	Oil, 650 PaS	Oil, 1050 PaS	Acrawax C
0		0	1	0	2
300	0	0	1	0	2
600	0	2	1	2	2
900	0	3	3	2	2
1200	0	4	3	3	3
1500	1		2	2	3
1800	1		3	3	3
2100	2		3	3	4
2400	3		3	3	4
2700	4		3	4	4
3000	4		3	4	

Teflon spray and Teflon grease

Figure 39 shows relative density as a function of total impact energy. Teflon in grease rendered samples with visibility index 2, but Teflon in an oil (spray) had visibility index 3.

5

The obtained relative densities of Teflon oil were higher than Teflon grease, but lots of material rests did stick to the tool surfaces of Teflon oil and no further testing was performed. The relative densities were similar of Acrawax C and Teflon grease to 600 Nm. At a higher impact energy the Acrawax C rendered a higher relative density than Teflon grease. At 2700 Nm both Acrawax C and Teflon grease received about the same relative density.

10

See table 7 for results of stickiness indexes of Teflon oil respectively grease.

15

TABLE 7

Total impact energy (Nm)	Stickiness index		
	Teflon oil	Teflon grease	Acrawax C
0	0	0	2
300	1	0	2
600	4	1	2
900		2	2
1200		2	3
1500		0	3
1800		0	3
2100		2	4
2400		3	4
2700		3	4
3000		3	4

Grease with white graphite added

Figure 40 shows relative density as a function of total impact energy. With lubricant where 3 wt% white graphite has been added to grease visibility index 2 was obtained. Where 9 wt% white graphite has been added to grease the samples had visibility index 3.

20

The obtained relative densities of all batches were very similar. There is no trend of what amount graphite that renders the highest relative density. But both these lubricants render a higher relative density, ~2 %, compared to Acrawax C.

- 5 See table 8 for results of stickiness indexes of grease with different amount of graphite added.

TABLE 8

Total impact energy (Nm)	Stickiness index		
	3 wt% graphite in grease	9 wt% graphite in grease	Acrawax C
0	1	1	2
300	1	1	2
600	1	1	2
900	2	2	2
1200	3	2	3
1500	4	3	3
1800	4	3	3
2100	4	3	4
2400	4	3	4
2700			4
3000			4

10

Grease with talc in different combinations

Figure 41 shows relative density as a function of total impact energy. All samples had visibility index 3.

- 15 The obtained relative densities of the batches were different. The samples where pure talc was powdered on the tool surfaces rendered a lower relative density compared with the other batches. It actually decreased between 900 and 1500 Nm. For the other batches the obtained relative density were similar. But there was an indication that grease with 9 wt% rendered the highest relative density, thereafter
- 20 Acrawax C, talc on pre-greased tool surfaces and the highest relative density with 3 wt% graphite.

See table 9 for results of stickiness indexes of grease with different amount of talc added.

TABLE 9

Total impact energy (Nm)	Stickiness index			
	Pure talc	Talc on pre-greased surfaces	Grease with 3 wt% talc	Grease with 9 wt% talc
0				
300	1	0	0	0
600				
900	5	1	0	0
1200				
1500	5	2	2	0
1800				
2100			2	0
2400				
2700		4	2	1
3000		5	2	1

5 LiX grease with different amount boron nitride added

Figure 42 shows relative density as a function of total impact energy. Some samples, where LiX grease with 5 wt% boron nitride consists as lubricant, had visibility index 2, for pre-compacting, 300, 600, 1500, 1800, 2100, 2400, 2700 Nm. The other lubricants rendered visibility index 3.

10

The obtained relative densities of the batches were irregular at low impact energies. All lubricants rendered about the same relative density. The stickiness index was different between the lubricants. Acrawax C started at a quite high stickiness index, 2, already from the beginning. Thereafter follow pure LiX, LiX with 5 wt% and LiX with 15 wt%.

15

See table 10 for results of stickiness indexes of LiX grease with different amount of boron nitride added.

TABLE 10

Total impact energy (Nm)	Stickiness index			
	LiX grease	LiX grease with 5 wt% boron nitride	LiX grease with 15 wt% boron nitride	Acrawax C
0	0	0	0	2
300	1	1	1	2
600	2	1		2
900	3	2		2
1200	4	3		3
1500	4	3		3
1800		3		3
2100		3		4
2400		4		4
2700				4
3000				4

5 Other types of greases and oils as lubricants

Figure 43 shows relative density as a function of total impact energy. The batch with MoS₂ grease as lubricant rendered samples with visibility index 2. The other batches, motor oil, lubrication oil, chain saw oil, lubrication grease and Acrawax C rendered visibility index 3.

10

The obtained relative densities of the batches were different. The batch with chain saw oil as lubricant rendered a lower relative density at all samples, but at 2700 Nm the relative density increases to a level of the obtained relative density with other lubricants. The tests with lubrication oil and lubrication grease stopped at 600 respectively 1200 Nm due to material rests on the tool surfaces. What can be seen is that Acrawax C renders the highest relative density and thereafter follow MoS₂, lubrication grease and motor oil.

15

Concerning the stickiness index Acrawax C begins at stickiness index 2.

20

Lubrication grease and oil begin at stickiness index 1, but the other bodies have visibility index 3. None of these lubricants rendered clean tool surfaces.

See table 11 for results of stickiness indexes of different greases and oils.

TABLE 11

Total impact energy (Nm)	Motor oil	MoS ₂	Lubrication oil	Chain saw oil	Lubrication grease	Acrawax C
0		0	0		0	2
300	0	0	0	2	1	2
600		2	3		3	2
900	1	2	4	2		2
1200		2			4	3
1500	3	2		3		3
1800		3				3
2100	3	3		4		4
2400		3				4
2700	5			4		4
3000	5			4		4

5

With oils, relative densities was lower than for other lubricants. Grease with 9 wt% talc obtained the highest relative density in this lubrication type test. It was even higher than Acrawax C. In the mean time grease with 9 wt% talc obtained the lowest stickiness index.

10

Another lubricant, MOLYKOTE, has been used for Co28Cr6Mo and compared with Acrawax C. MOLYKOTE showed to give better relative density, however, MOLYKOTE is not suitable to use in medical products and it is not possible to sinter away.

15

It is shown that the external lubricant affects both the relative density and the stickiness to the tool surfaces. Some lubricants possibly decrease the friction between the tool surfaces and the powder. In these cases a higher relative density could possibly be obtained compared with lubricants with a high friction. With low friction the stroke unit is able to perform its stroke with the installed impact energy and higher density could be obtained. However, the result of the lubricant is in many cases different in two ways. If a lubricant increases the relative density, it may not be so good for the stickiness to the mould and vice versa. However, grease

20

with 90 % talc obtained both high relative density and low stickiness index, which is a great advantage.

The hardness of the materials seems to affect the results. The softer a material is the more soften and deformed the particles get. That enables the particles to get softened, deformed and compacted before the inter-particle melting occurs. A difference can be seen in the energy and additive studies between Co₂₈Cr₆Mo and the other materials. The hardness of Co₂₈Cr₆Mo is ~460-830 HV, which is much higher than the hardness of the other materials, and e.g. titanium, 60 HV, and low wrought steel, 130-280 HV. The difference of the visibility index, described below in the examples, gives an indication of the results among the tested metal types and with the hardness. In some of the batches included in the energy and additive studies, carbon has been alloyed in the manufacturing process of the powder to increase the hardness of the final component. To decrease the hardness of the powder, without necessary change the properties of the final component, the powder could be soft annealed. This pre-treated powder could possibly enable an even higher relative density. Some of the other materials are hard as well, but e.g. tool steel has been soft annealed and that enabled to increase the obtained relative density.

20

The melting temperature seems to affect the grade of compacting of the material. For instance the melting temperature of aluminium alloy is one third of e.g. nickel alloy. In the energy and additive studies all aluminium alloy batches reached high relative densities. Nickel alloy is, on the contrary, difficult to succeed in obtaining high relative density. This parameter could be one among others that effect the grade of compaction.

25

A new method is shown which comprises both pre-compacting and in some cases post-compacting and there between at least one stroke on the material. The new method has shown to give very good results and is an improved process according to prior art.

30

The invention is not limited to the above described embodiments and examples. It is an advantage that the present process does not require the use of sintering aids neither to produce a coherent green body and it makes it possible to use a lower sintering temperature. However, it is possible to use sintering aids, lubricant or other additives in the process of the invention if this should prove advantageous in some embodiments. Likewise, it is usually not necessary to use vacuum or an inert gas to prevent oxidation of the material body being compressed. However, some materials may require vacuum or an inert gas to produce a body of extreme purity or high density. Thus, although the use of sintering aids, vacuum and inert gas are not required according to the invention the use thereof is not excluded. Other modifications of the method and product of the invention may also be possible within the scope of the following claims.

Claims

1. A method of producing a metal body by coalescence, **characterised** in that the method comprises the steps of
 - 5 a) filling a pre-compacting mould with metal material in the form of powder, pellets, grains and the like,
 - b) pre-compacting the material at least once and
 - c) compressing the material in a compression mould by at least one stroke, where a striking unit emits enough kinetic energy to form the body when striking the
- 10 material inserted in the compression mould, causing coalescence of the material.
2. A method according to claim 1, **characterised** in that the pre-compacting mould and the compressing mould are the same mould.
3. A method according to any of the preceding claims for producing a body of stainless steel, **characterised** in that the material is pre-compacted with a
- 15 pressure of at least about $0.25 \times 10^8 \text{ N/m}^2$, in air and at room temperature.
4. A method according to claim 3, **characterised** in that the material is pre-compacted with a pressure of at least about $0.6 \times 10^8 \text{ N/m}^2$.
5. A method according to any of the preceding claims, **characterised** in that the method comprises pre-compacting the material at least twice.
- 20 6. A method of producing a metal body by coalescence, **characterised** in that the method comprises compressing material in the form of a solid metal body in a compression mould by at least one stroke, where a striking unit emits enough energy to cause coalescence of the material in the body.
7. A method according to any of claims 1-5 or claim 6, **characterised** in that the
- 25 compression strokes emit a total energy corresponding to at least 100 Nm in a cylindrical tool having a striking area of 7 cm^2 in air and at room temperature.
8. A method according to claim 7, **characterised** in that the compression strokes emit a total energy corresponding to at least 300 Nm in a cylindrical tool having a striking area of 7 cm^2 .

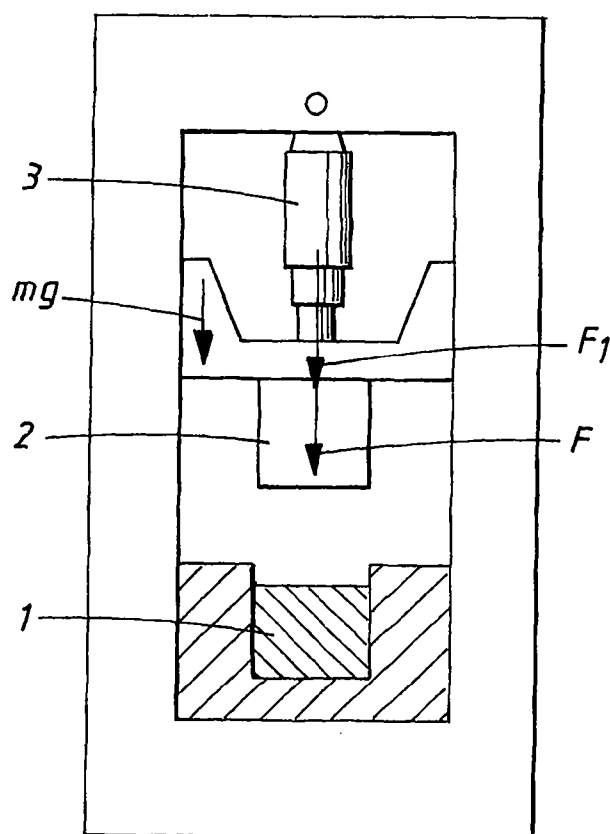
9. A method according to claim 8, **characterised** in that the compression strokes emit a total energy corresponding to at least 600 Nm in a cylindrical tool having a striking area of 7 cm².
10. A method according to claim 9, **characterised** in that the compression strokes
5 emit a total energy corresponding to at least 1000 Nm in a cylindrical tool having a striking area of 7 cm².
11. A method according to claim 10, **characterised** in that the compression strokes emit a total energy corresponding to at least 2000 Nm in a cylindrical tool having a striking area of 7 cm².
- 10 12. A method according to any of claim 1-5 or claim 6, **characterised** in that the compression strokes emit an energy per mass corresponding to at least 5 Nm/g in a cylindrical tool having a striking area of 7 cm² in air and at room temperature.
13. A method according to claim 12, **characterised** in that the compression strokes
15 emit an energy per mass corresponding to at least 20 Nm/g in a cylindrical tool having a striking area of 7 cm².
14. A method according to claim 13, **characterised** in that the compression strokes emit an energy per mass corresponding to at least 100 Nm/g in a cylindrical tool having a striking area of 7 cm².
- 20 15. A method according to claim 14, **characterised** in that the compression strokes emit an energy per mass corresponding to at least 250 Nm/g in a cylindrical tool having a striking area of 7 cm².
16. A method according to claim 15, **characterised** in that the compression strokes emit an energy per mass corresponding to at least 450 Nm/g in a cylindrical tool
25 having a striking area of 7 cm².
17. A method according to any of the preceding claims, **characterised** in that the metal is compressed to a relative density of at least 70 %, preferably 75 %.
18. A method according to claim 17, **characterised** in that the metal is compressed to a relative density of at least 80 %, preferably 85 %.
- 30 19. A method according to claim 18, **characterised** in that the metal is compressed to a relative density of at least 90 % to 100 %.

20. A method according to any of the preceding claims, **characterised** in that the method comprises a step of post-compacting the material at least once after the compression step.
21. A method according to any of the preceding claims, **characterised** in that the
5 metal is chosen from the group comprising light metal or alloy, ferrous based alloy, non ferrous alloy and hard melting metal or hard alloy.
22. A method according to claim 21, **characterised** in that the metal is chosen from the group comprising aluminium, titanium and alloys containing at least one of those.
- 10 23. A method according to claim 21, **characterised** in that the ferrous based alloy is chosen from the group comprising stainless steel, martensitic steel, low wrought steel and tool steel.
24. A method according to claim 21, **characterised** in that the high melting metal or hard alloy is chosen from the group comprising Co, Cr, Mo and Ni as well as
15 alloys containing at least one of those.
25. A method according to any of the preceding claims, **characterised** in that the body produced is a medical implant, such as a skeletal or tooth prosthesis.
26. A method according to any of the preceding claims, **characterised** in that the method comprises a step of post-heating and/or sintering the body any time after
20 the compression or the post-compacting.
27. A method according to any of the preceding claims, **characterised** in that the body produced is a green body.
28. A method of producing a body according to claim 27, **characterised** in that the method also comprises a further step of sintering the green body.
- 25 29. A method according to any of the preceding claims, **characterised** in that the material is a medically acceptable material.
30. A method according to any of the preceding claims, **characterised** in that the material comprises a lubricant and/or a sintering aid.
31. A method according to claim 6, **characterised** in that the method also comprises
30 deforming the body.
32. A product obtained by the method according to any of claims 1-31.

33. A product according to claim 32, **characterised** in being a medical device or instrument.

34. A product according to claim 32, **characterised** in being a non medical device.

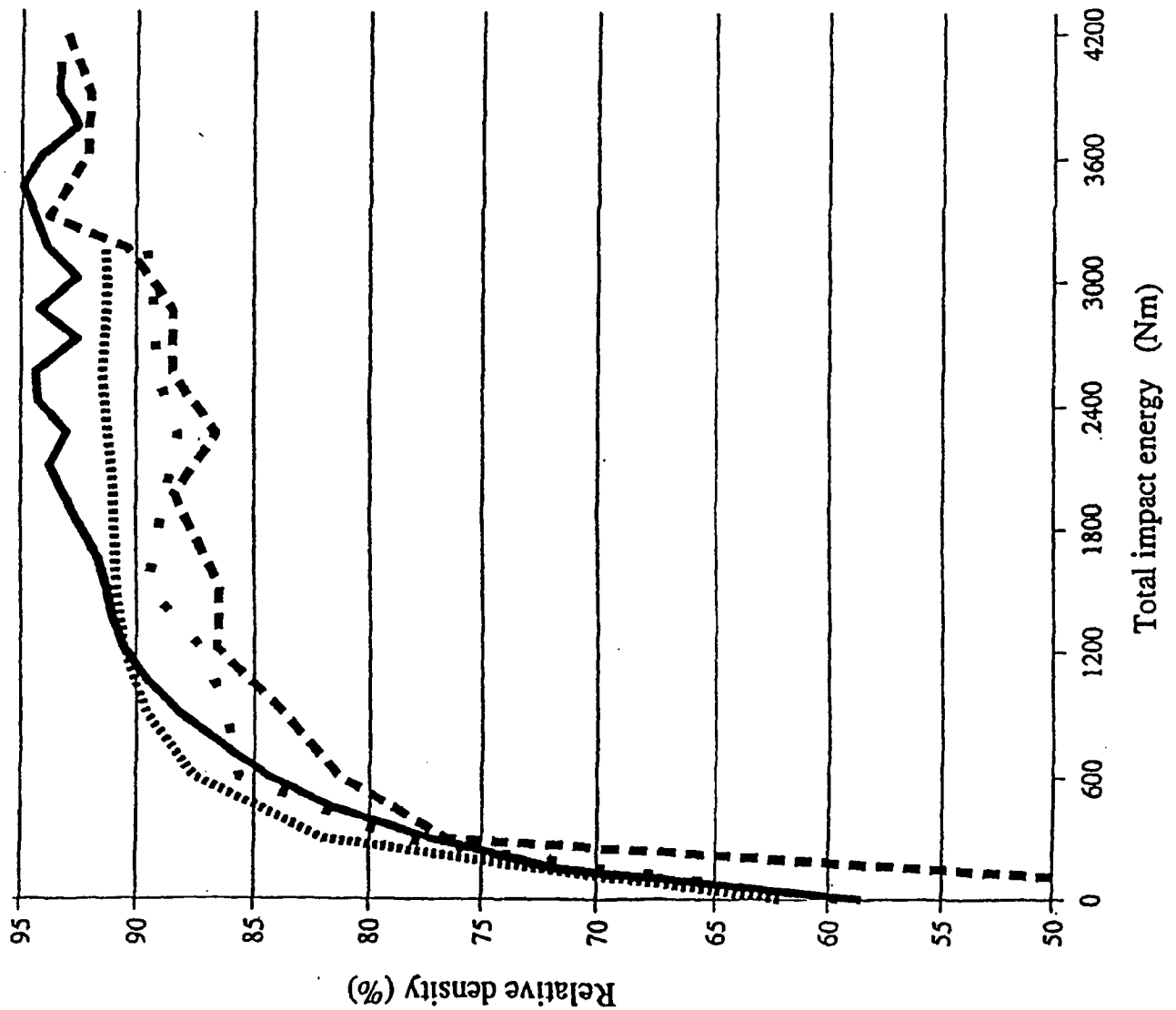
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Fig. 1

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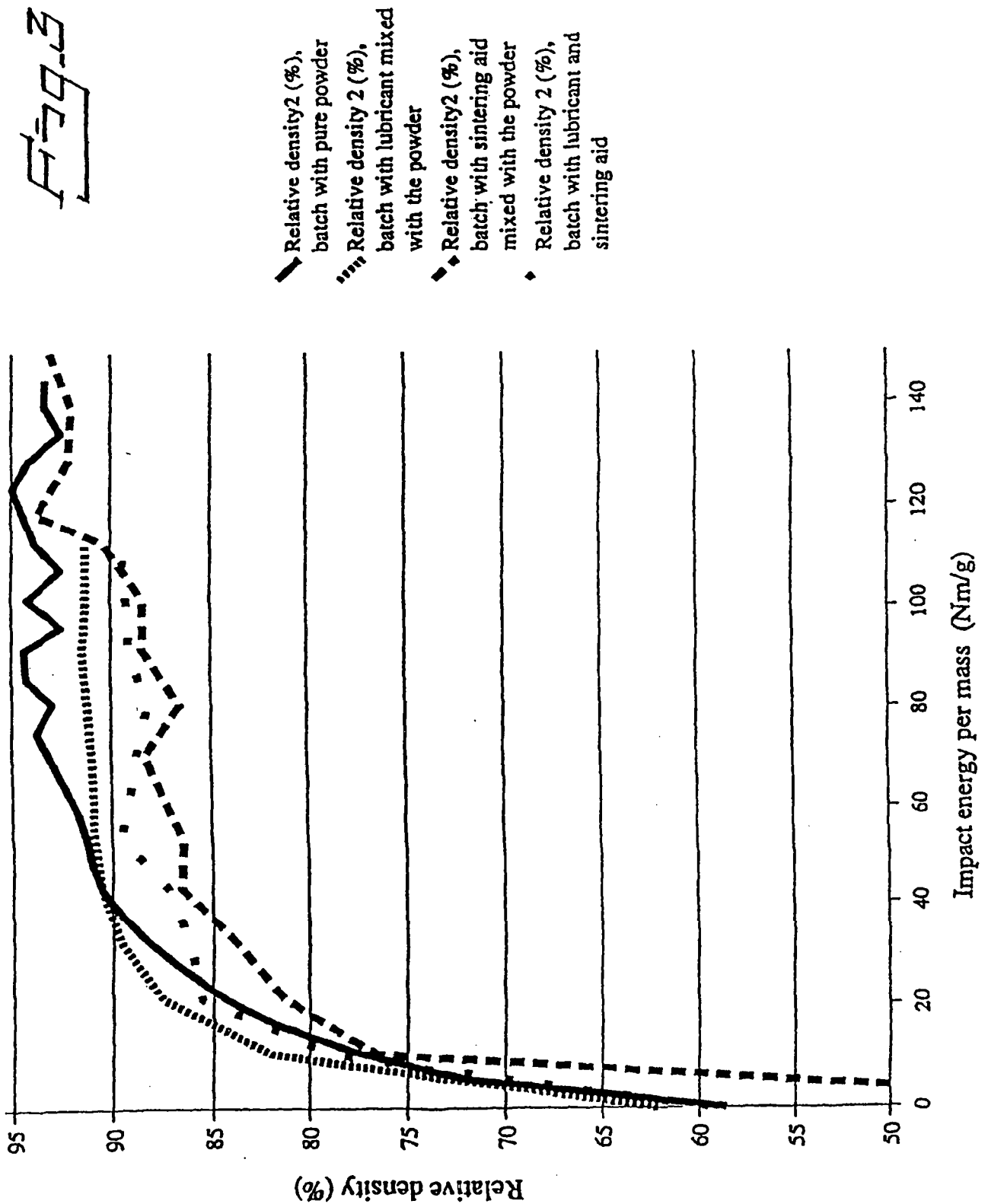
Fig. 2

- Relative density 2 (%), batch with pure powder
- Relative density 2 (%), batch with lubricant mixed with the powder
- - - Relative density 2 (%), batch with sintering aid mixed with the powder
- ♦ Relative density 2 (%), batch with lubricant and sintering aid



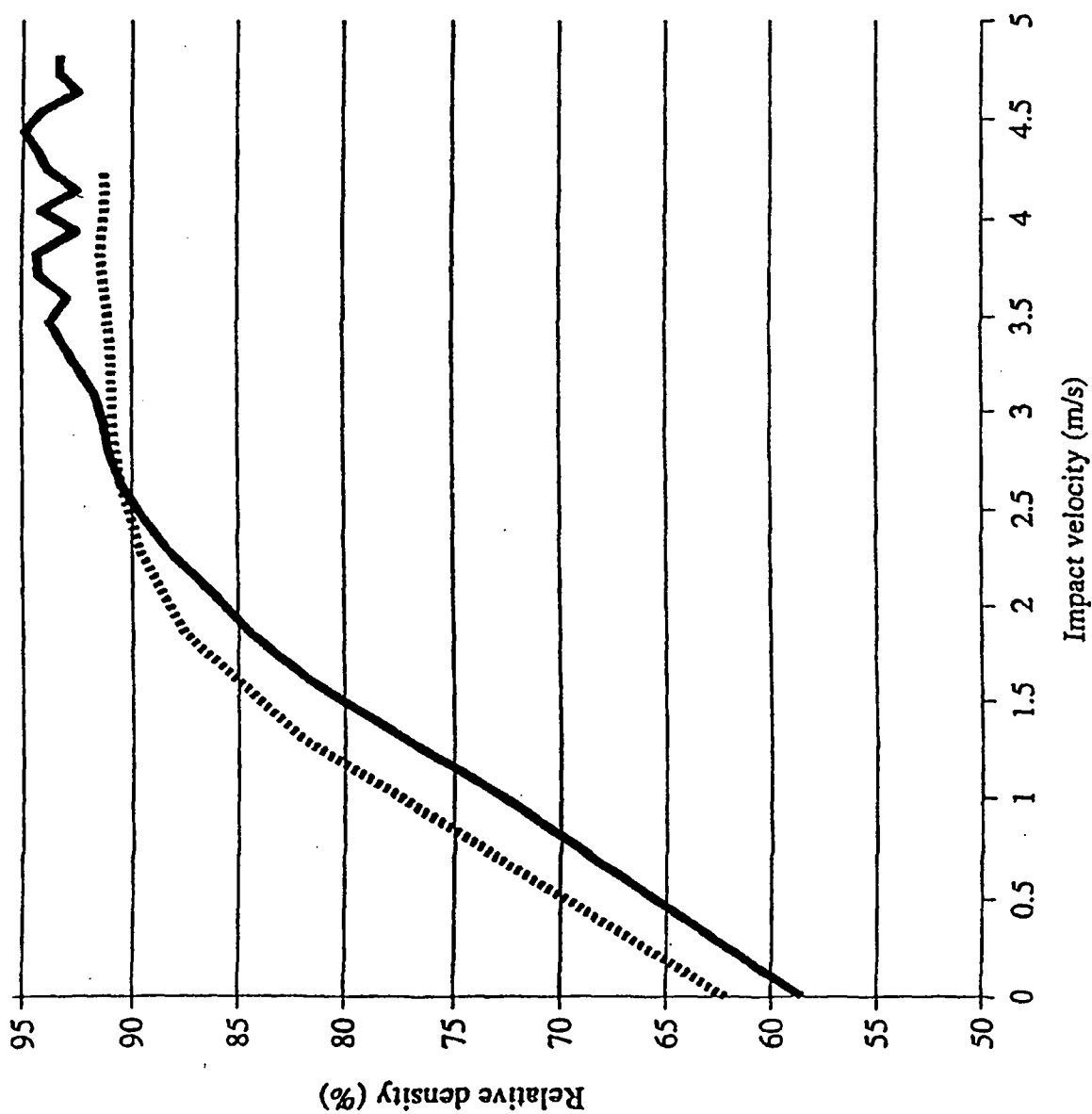
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Fig. 3



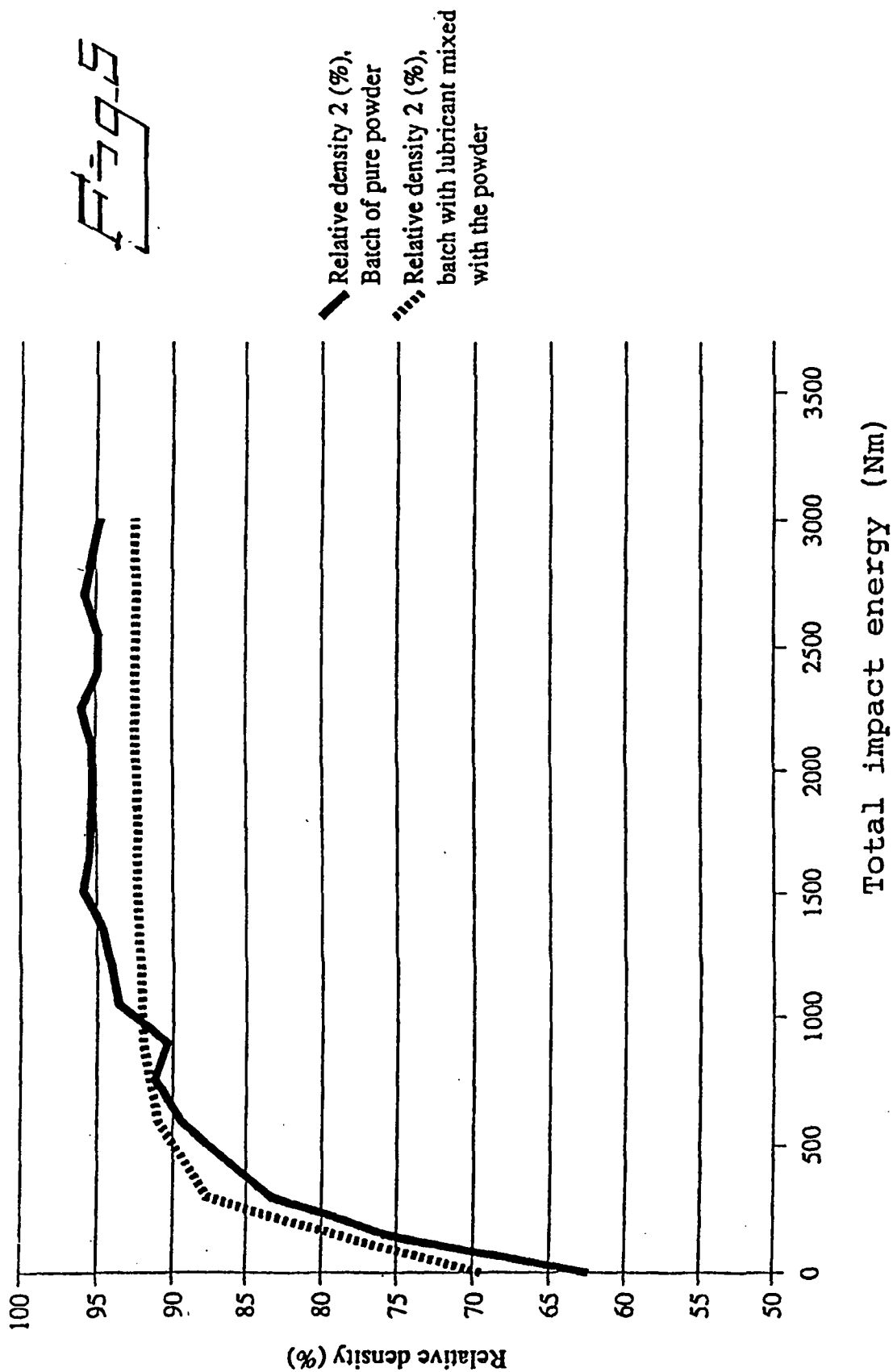
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Fig. 4



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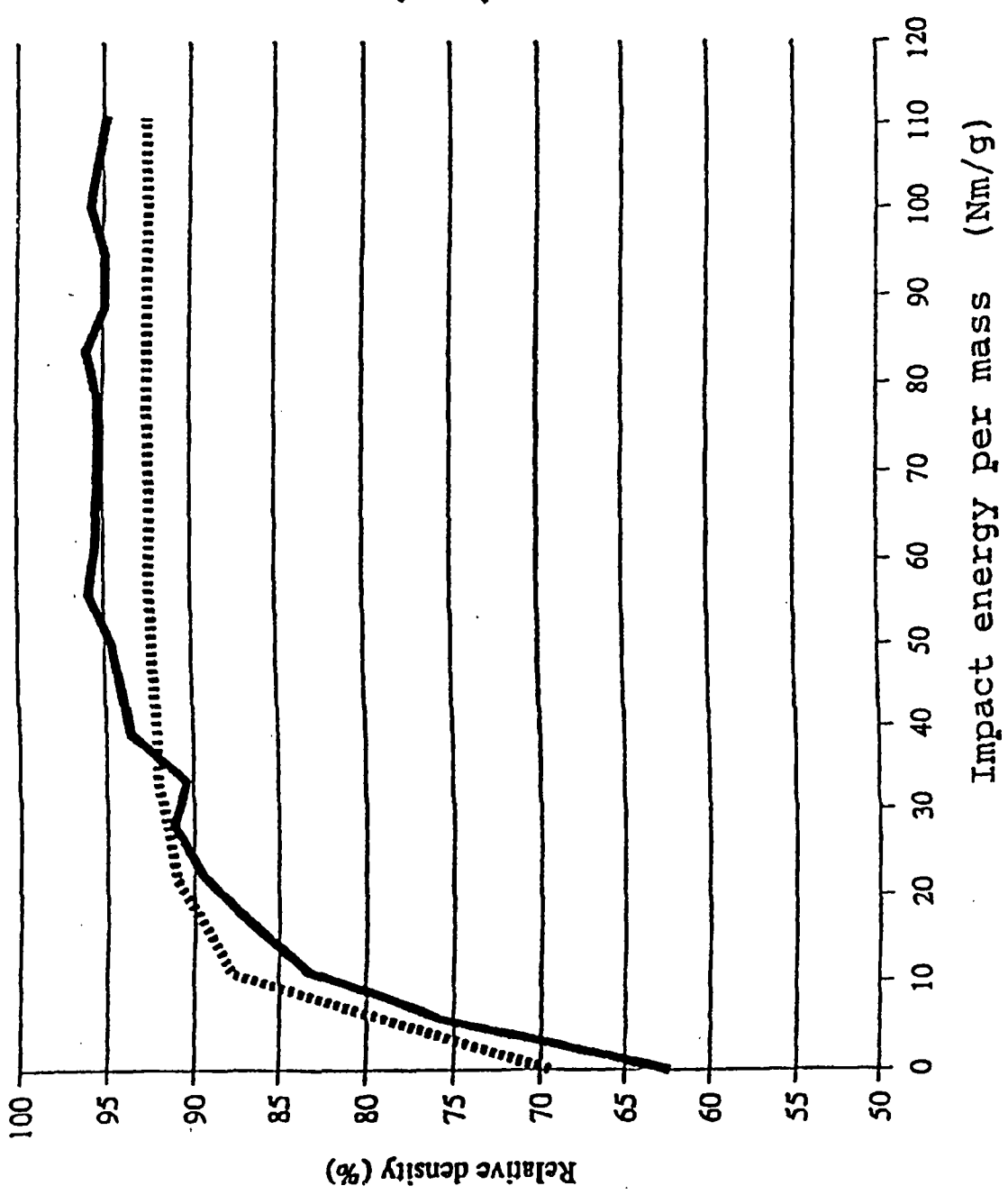
Fig. 5



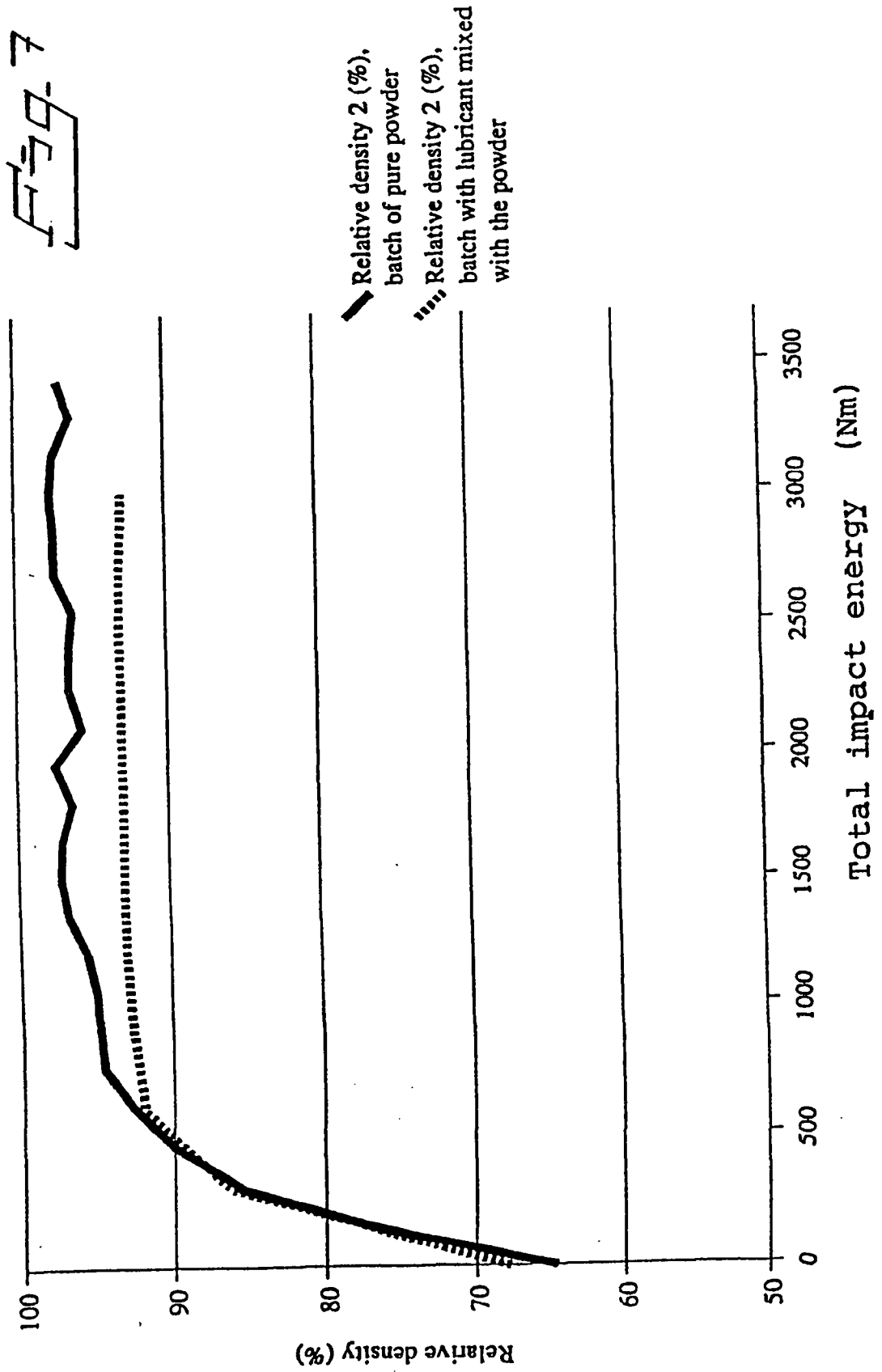
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Fig. 6

Relative density 2 (%),
Batch of pure powder
Relative density 2 (%),
batch with lubricant mixed
with the powder

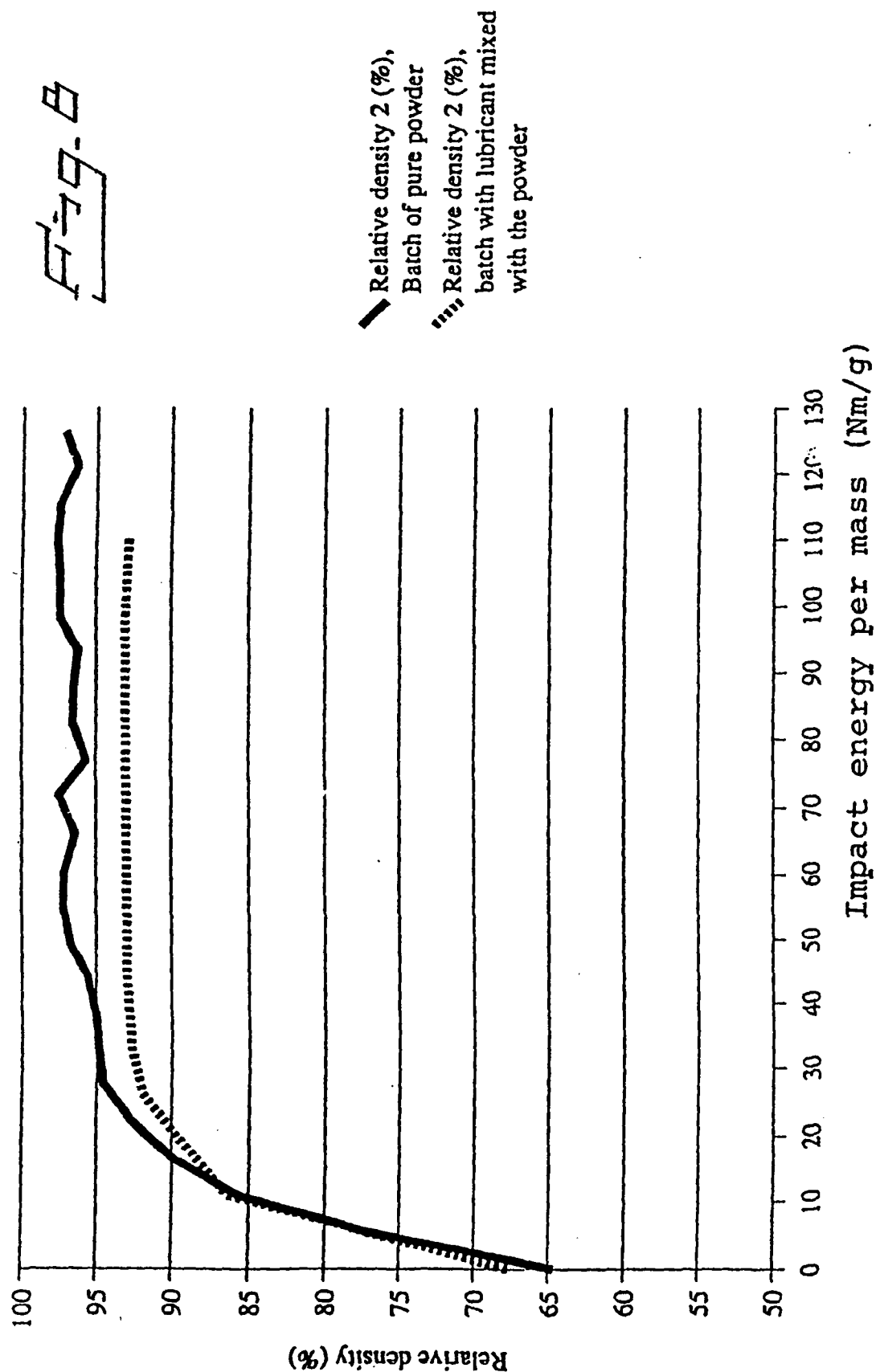


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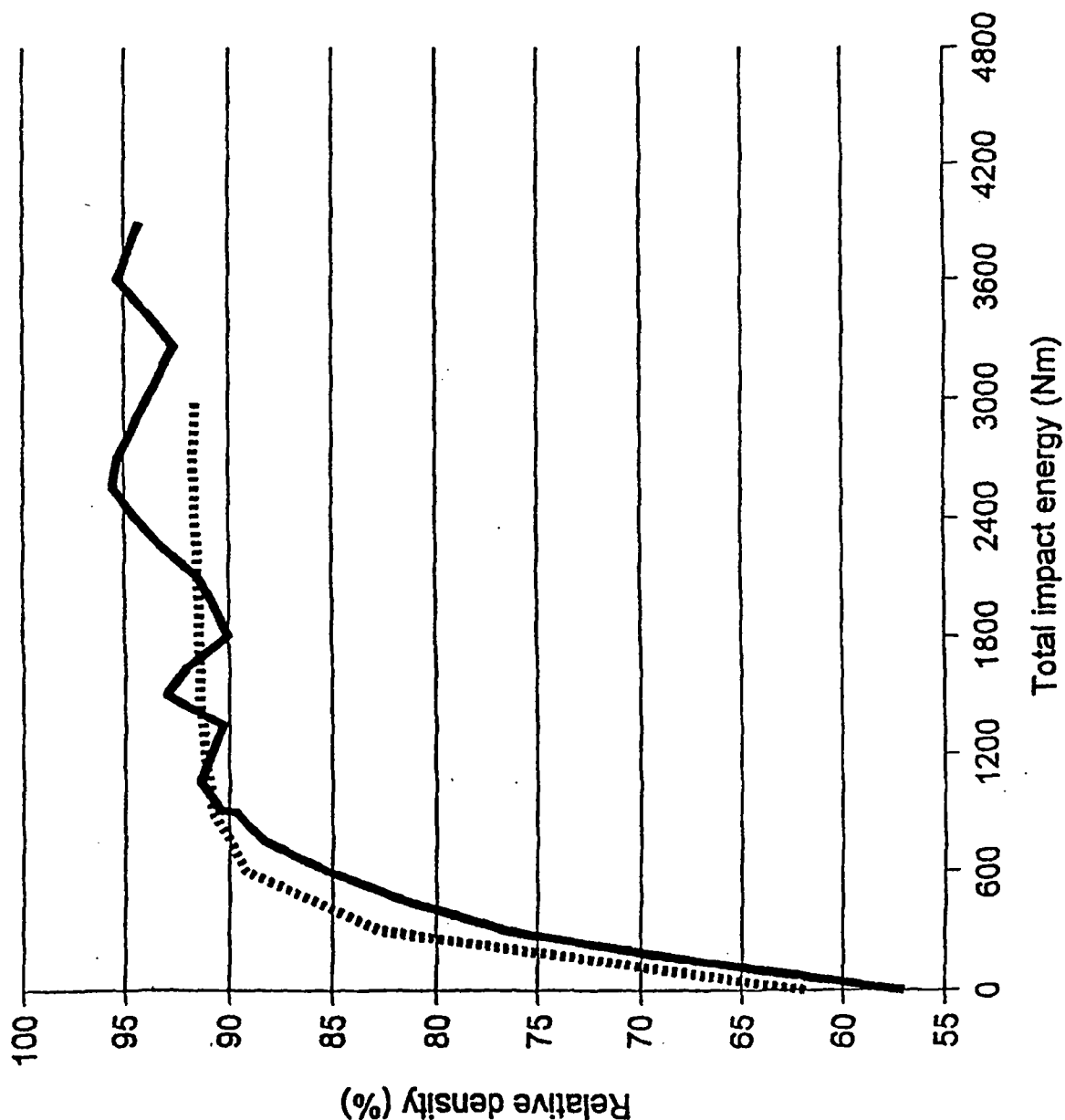
Fig. 8



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Fig. 9

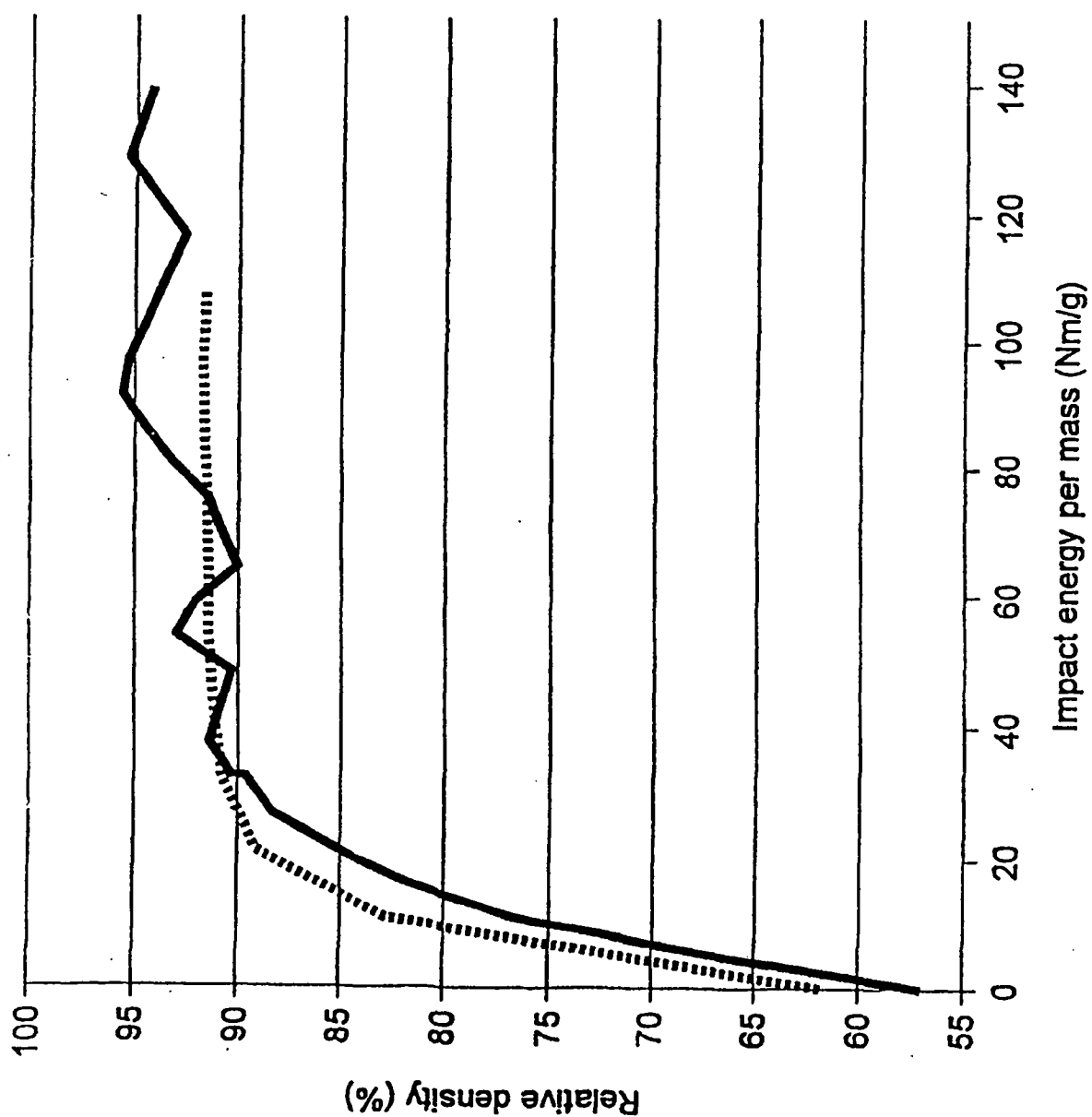
— Relative density 2 (%),
batch with pure powder
..... Relative density 2 (%),
batch with powder
containing lubricant



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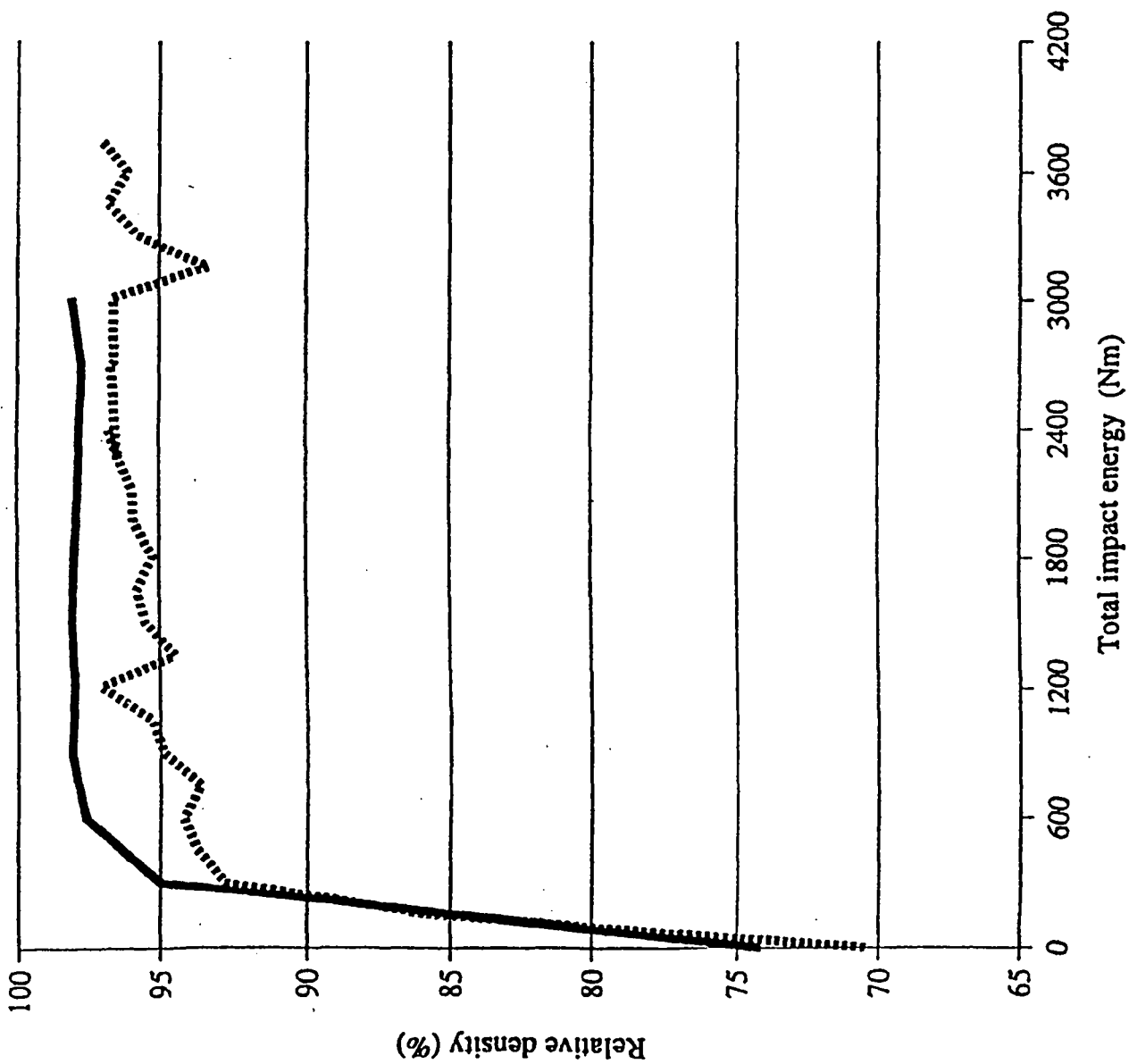
Fig. 10

— Relative density 2 (%),
batch with pure powder
..... Relative density 2 (%),
batch with powder
containing lubricant



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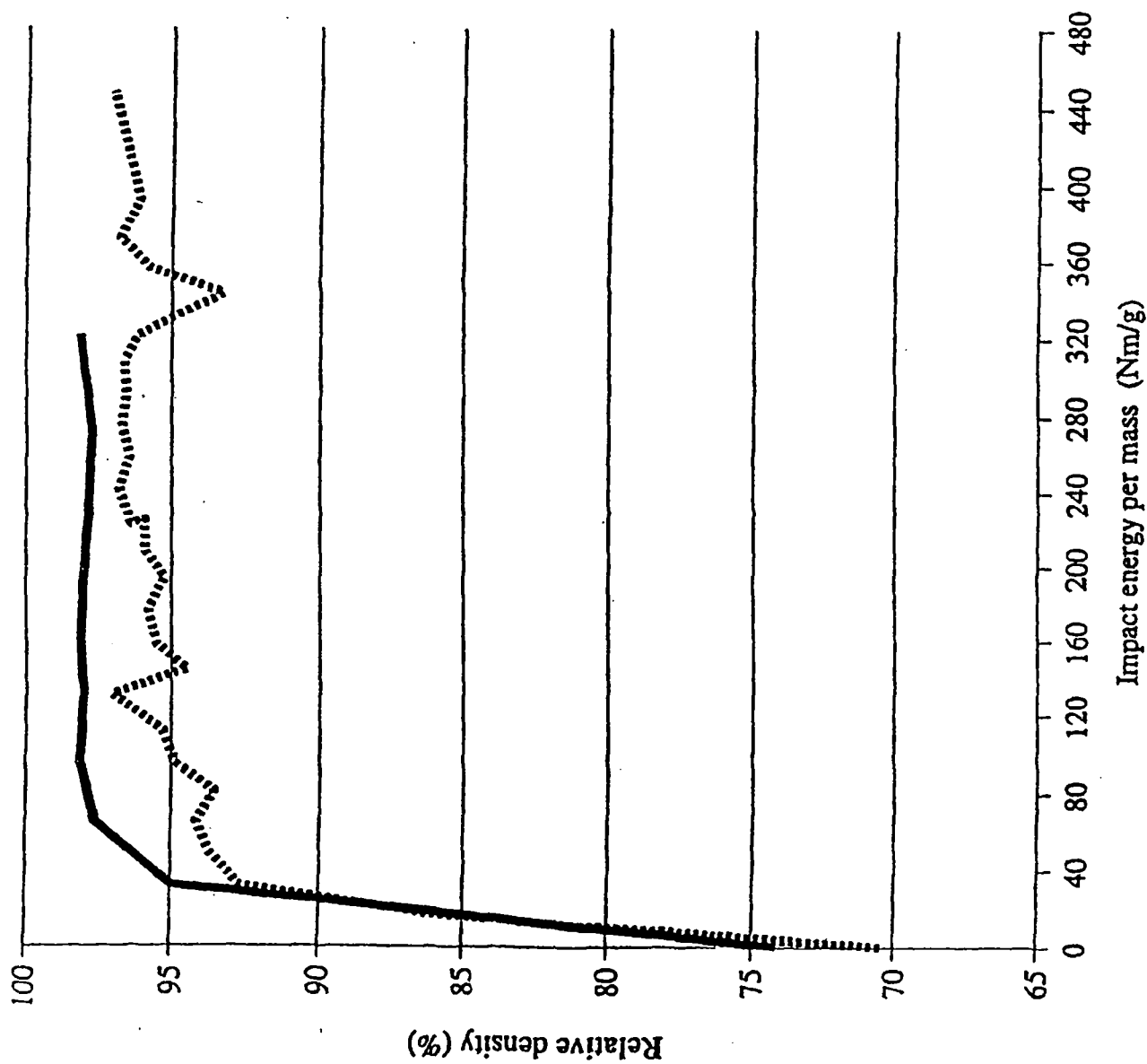
Fig. 11



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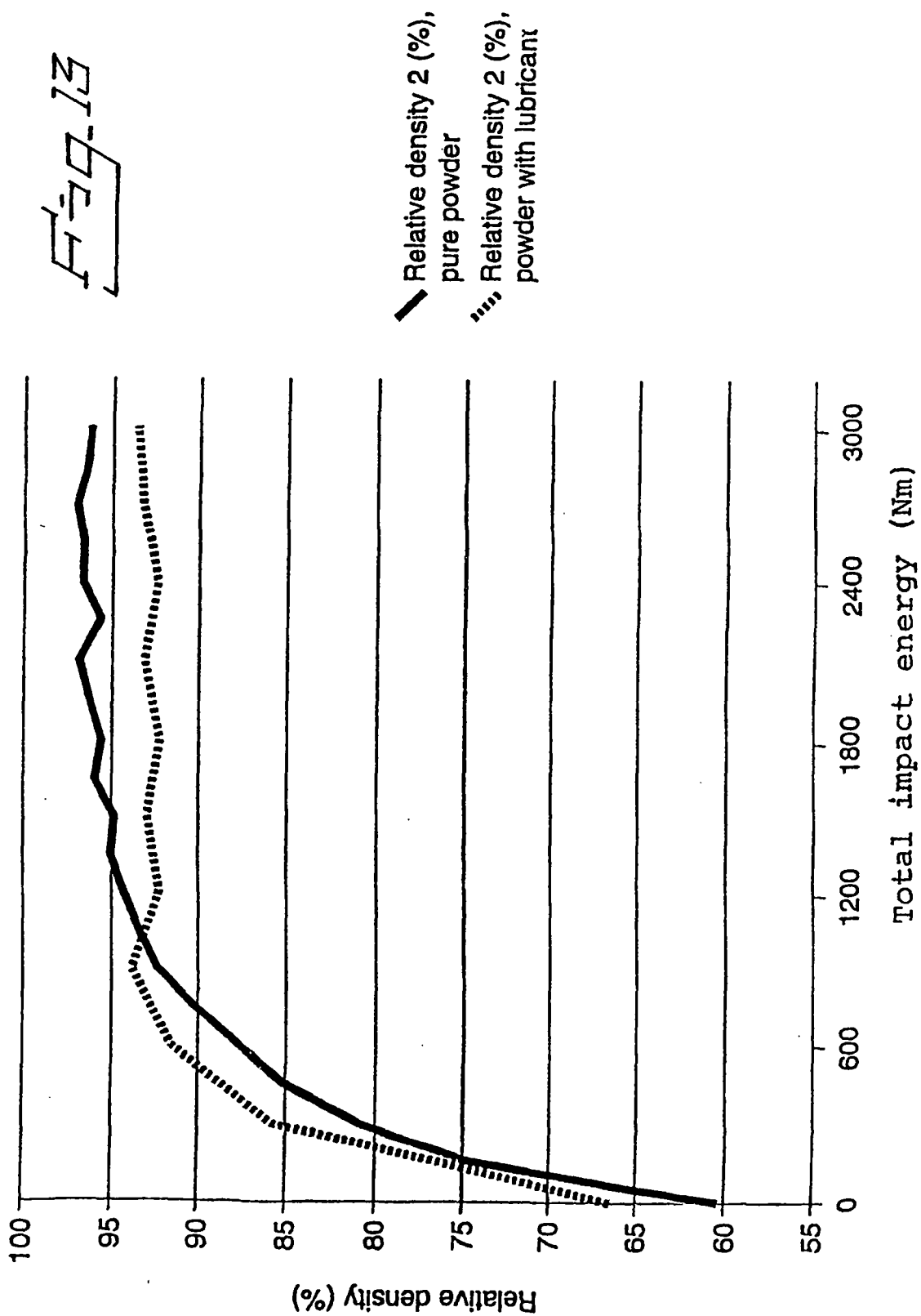
Fig. 12

..... Relative density 2 (%),
batch with pure powder
—— Relative density 2 (%),
batch with lubricant
mixed with the powder



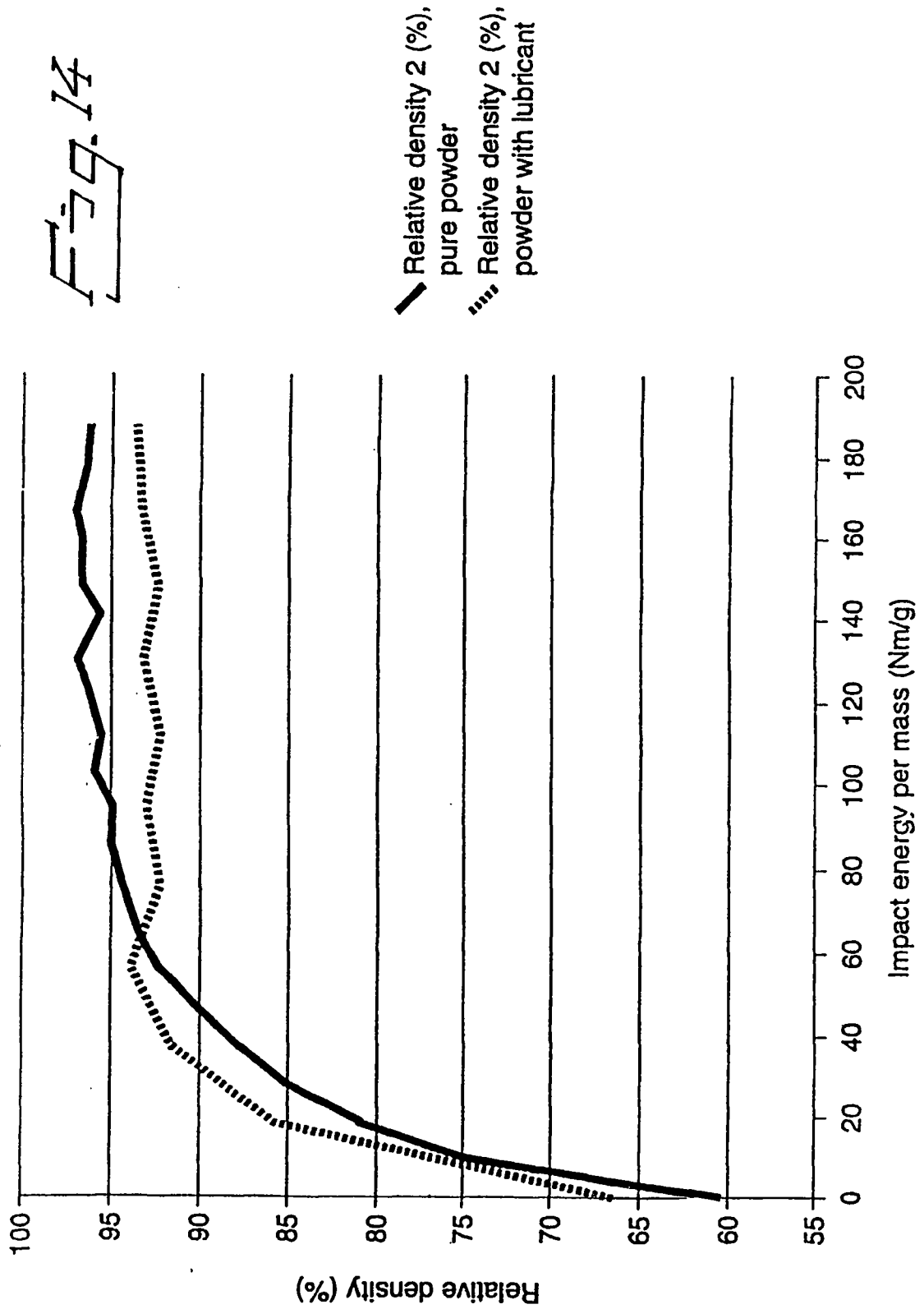
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Fig. 13



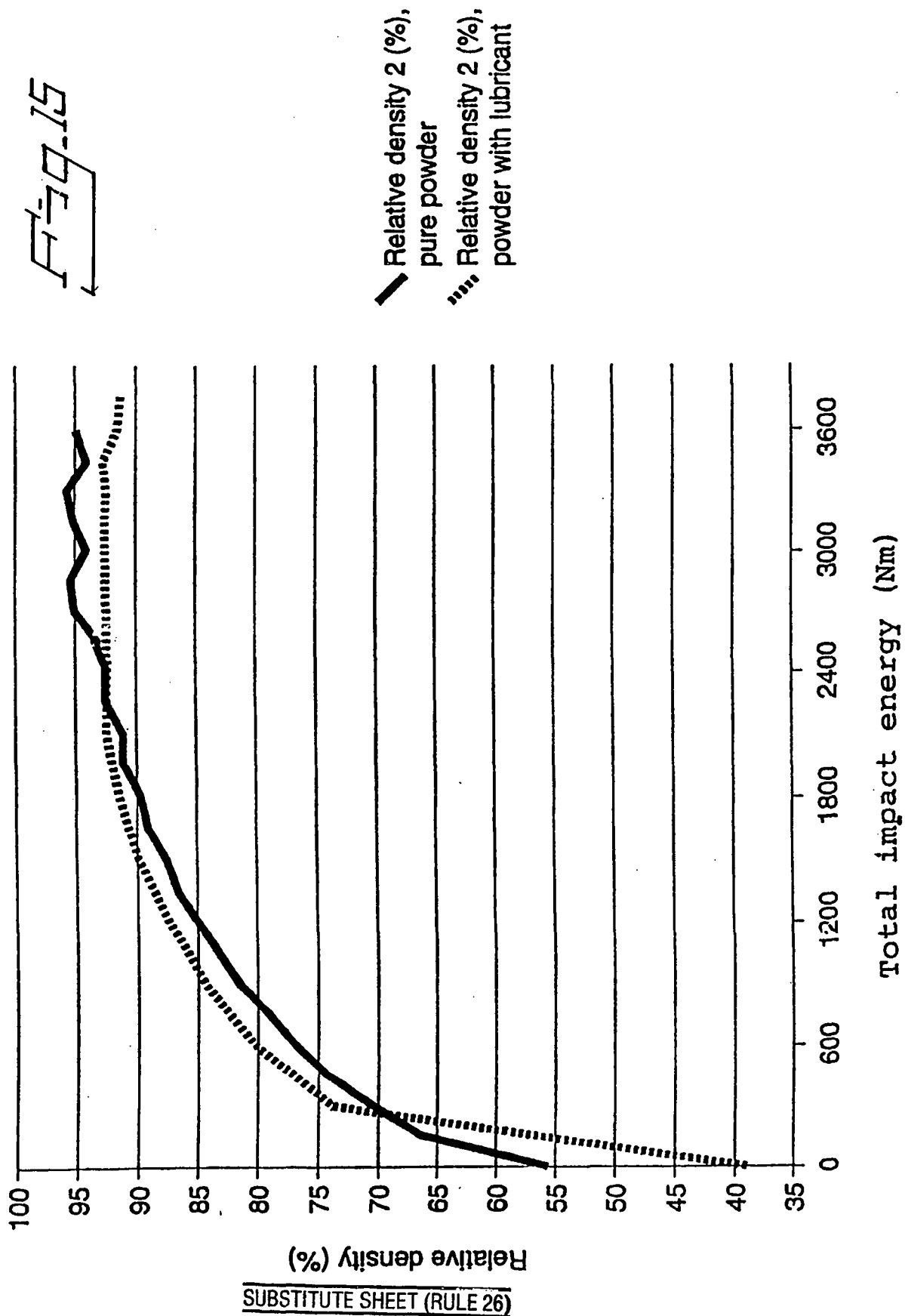
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Fig. 14



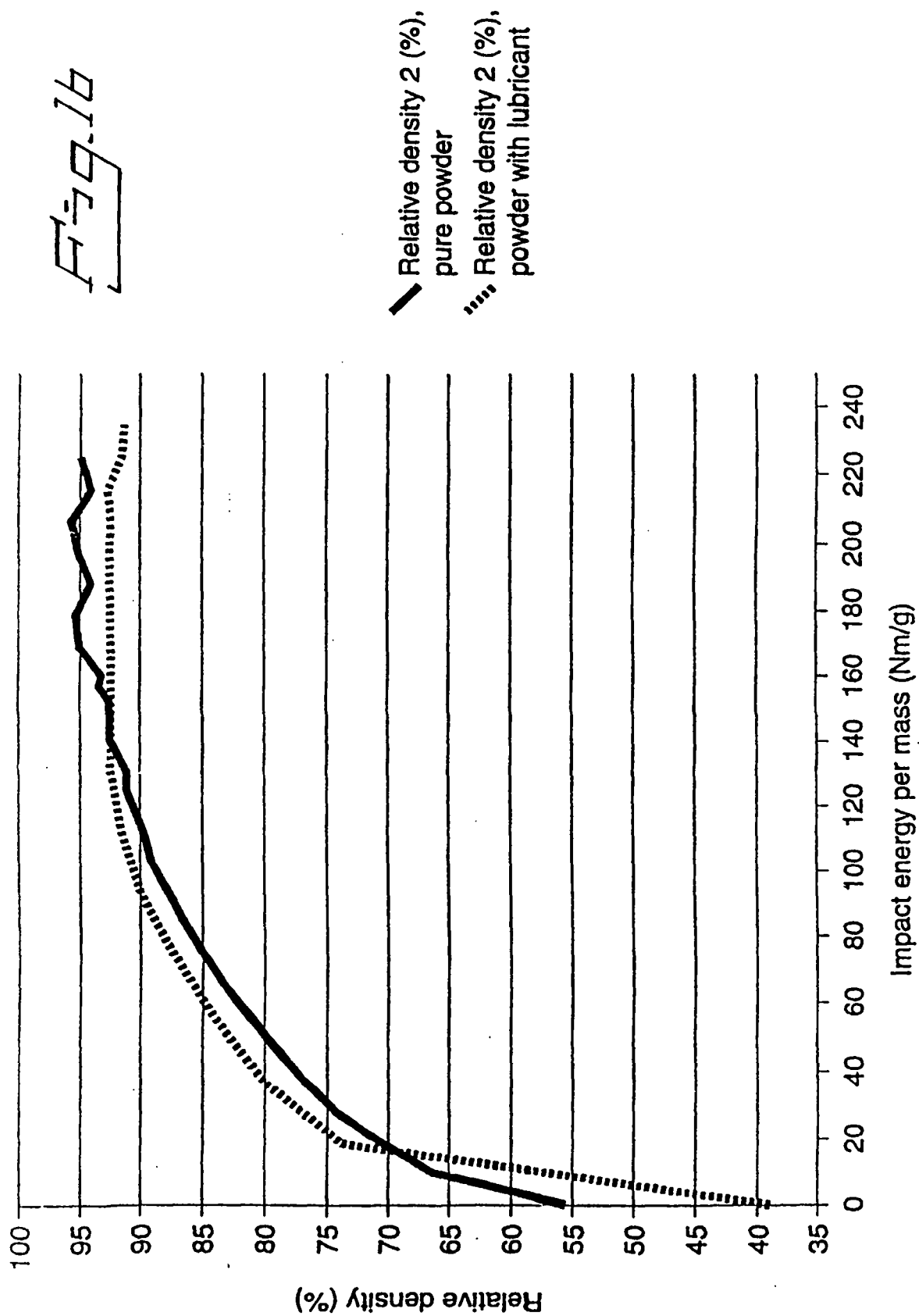
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Fig. 15



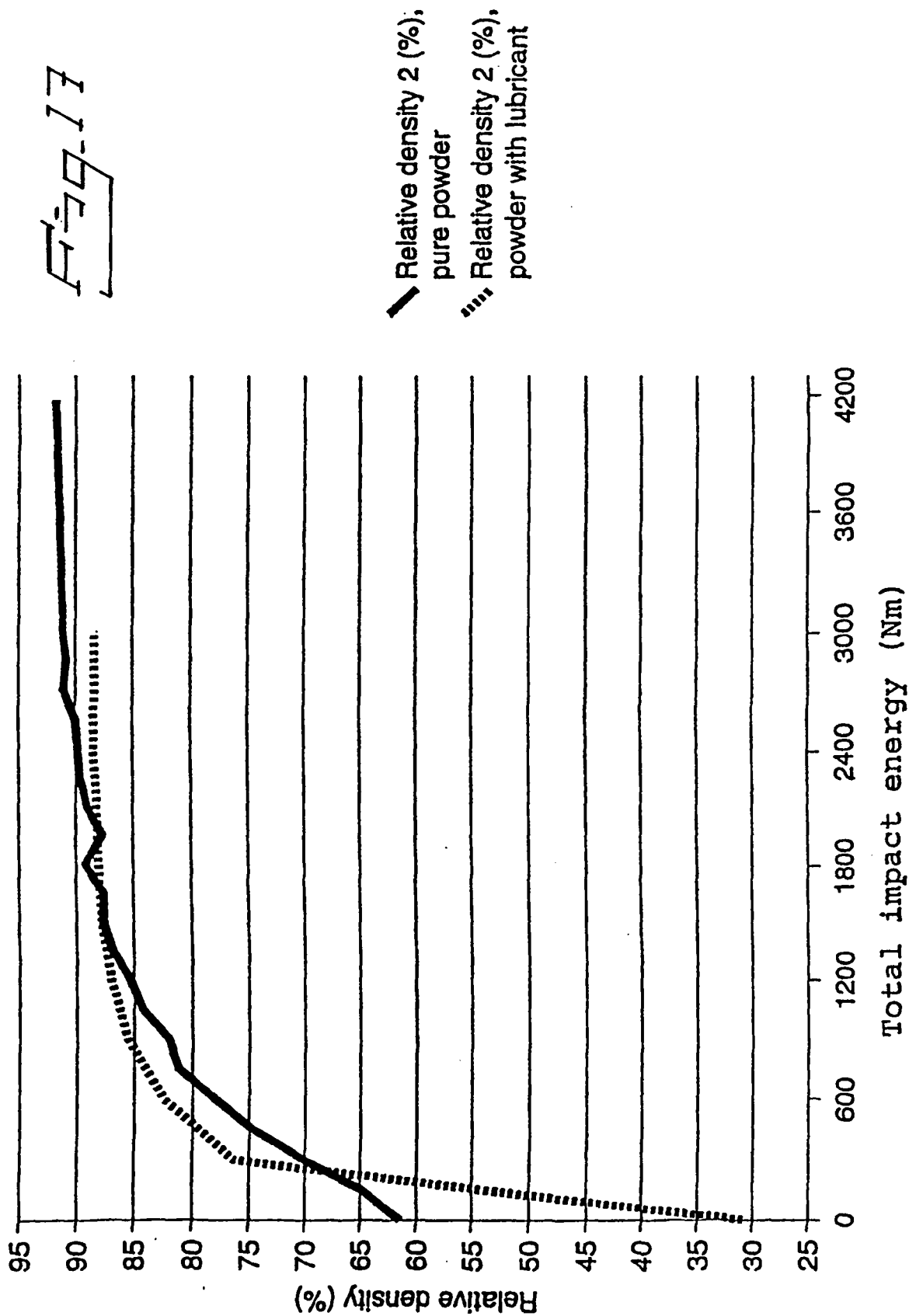
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Fig. 1b



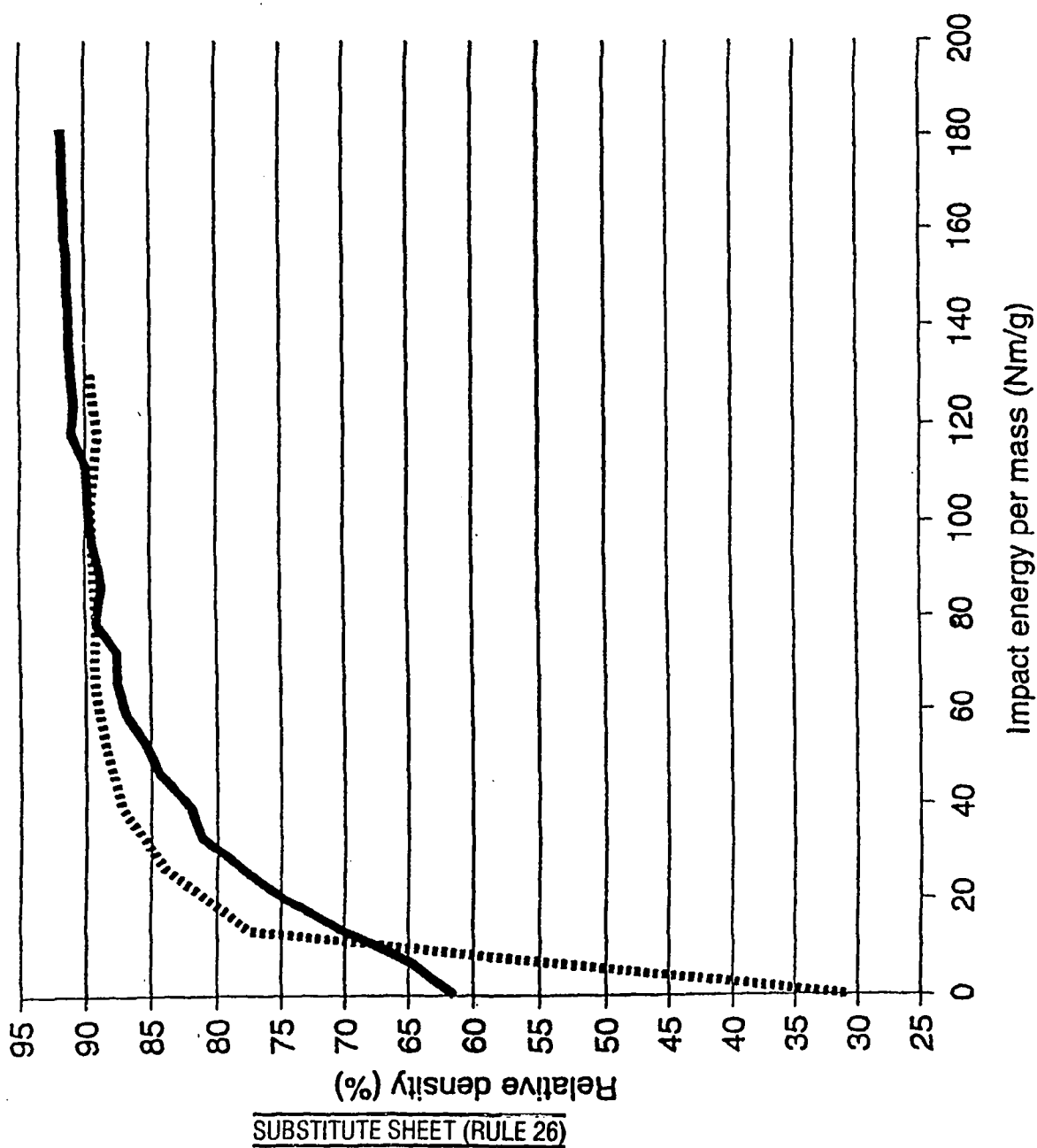
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Fig. 17



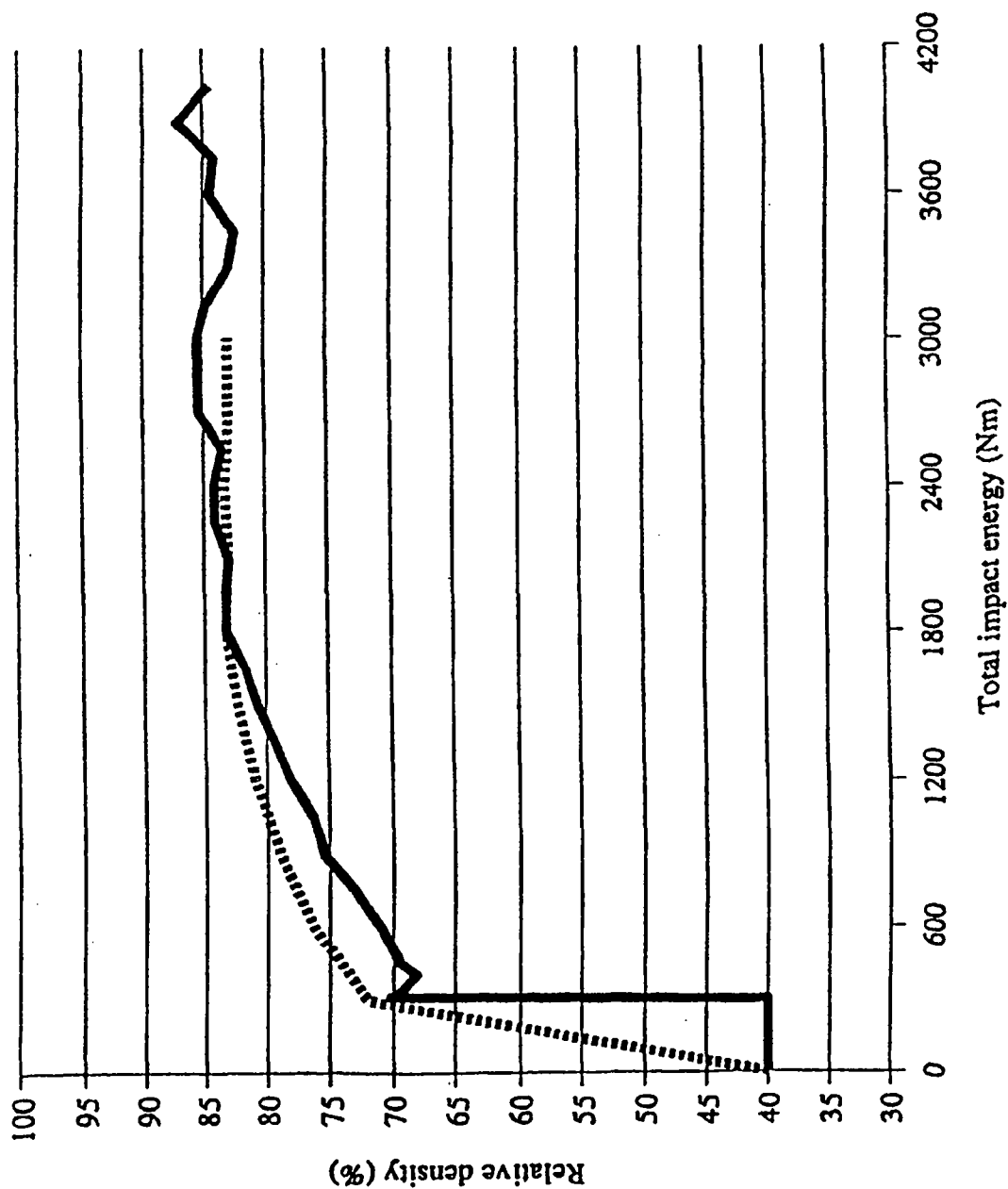
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Fig. 1B



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Fig. 19



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Fig. 20

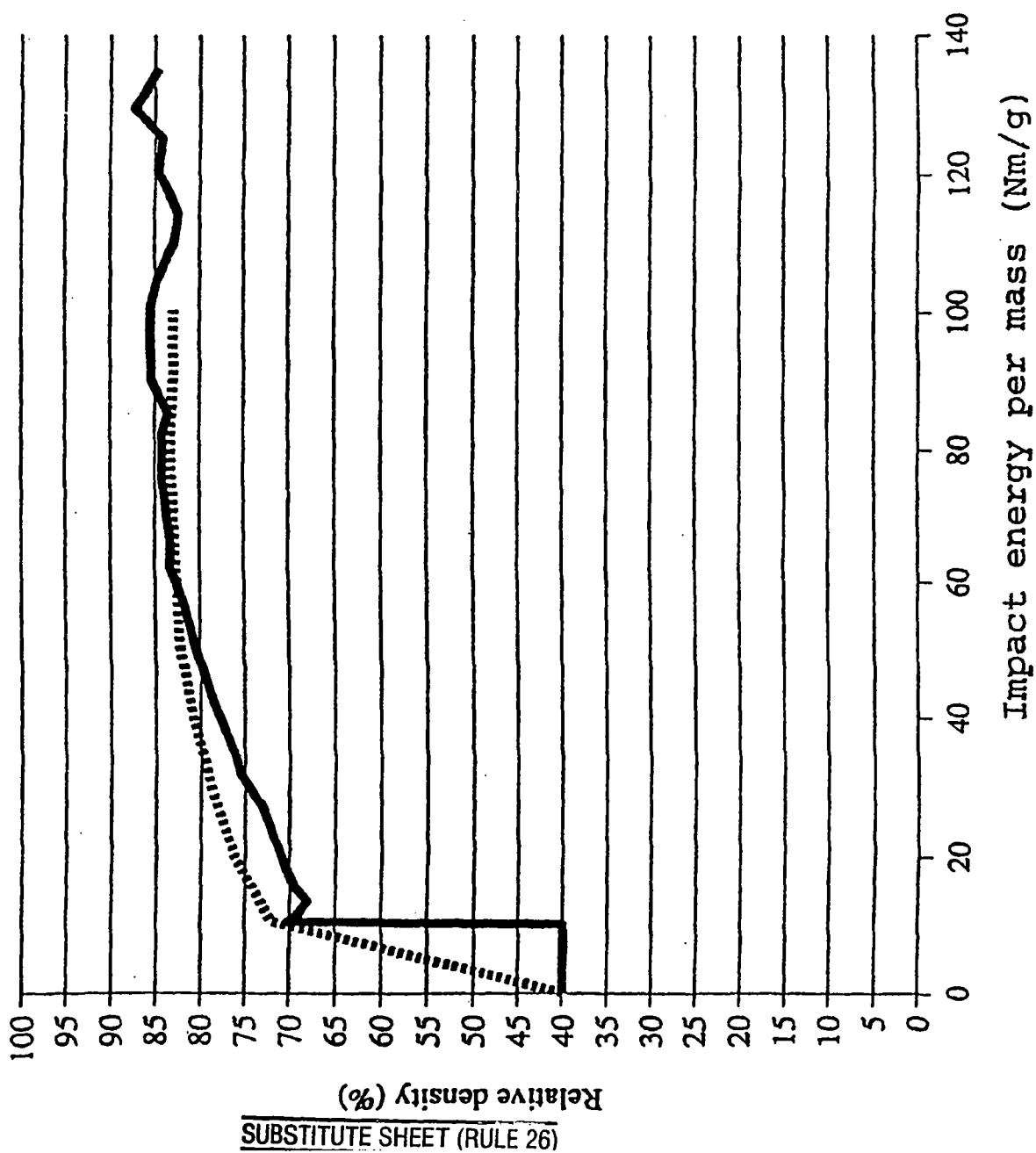
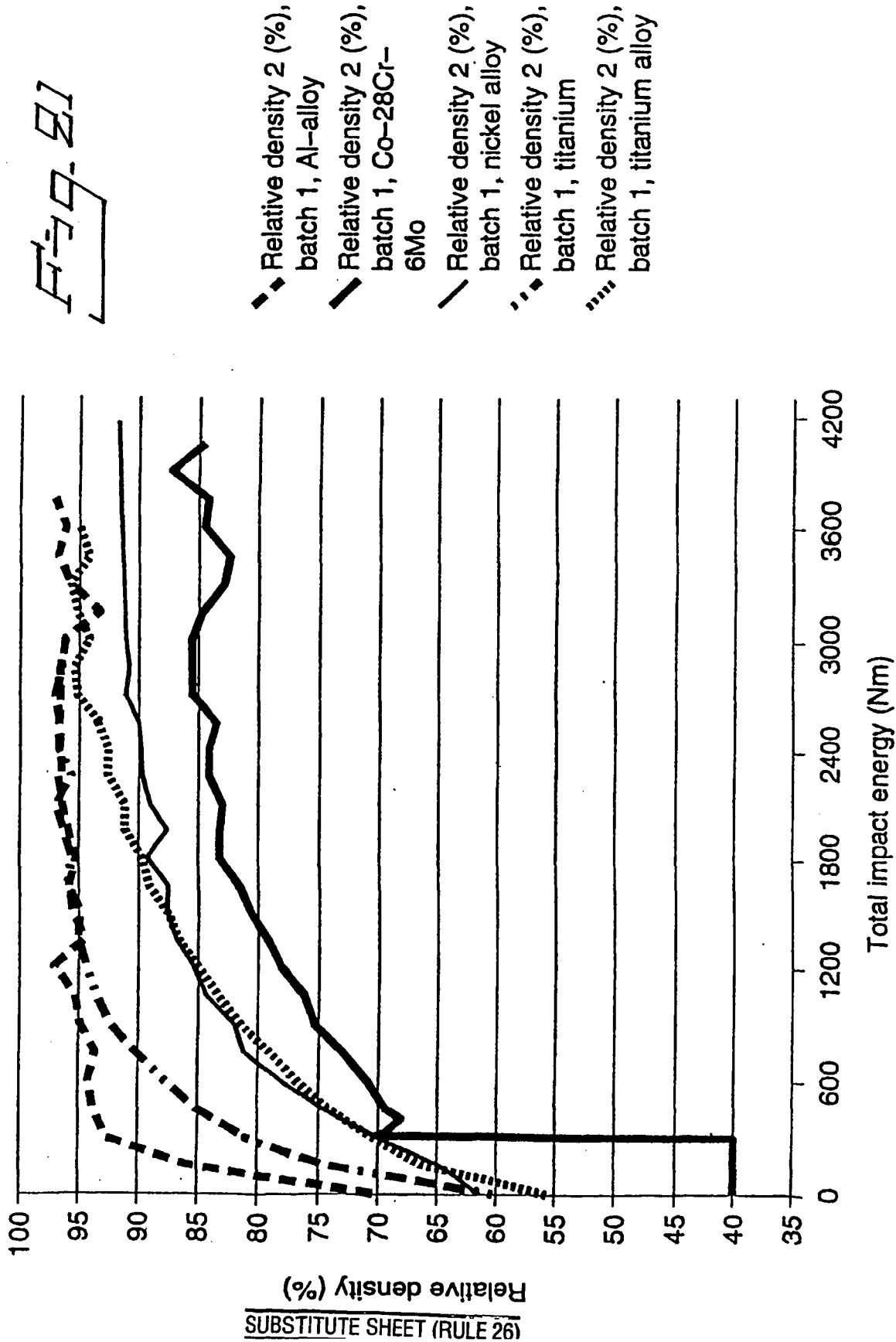
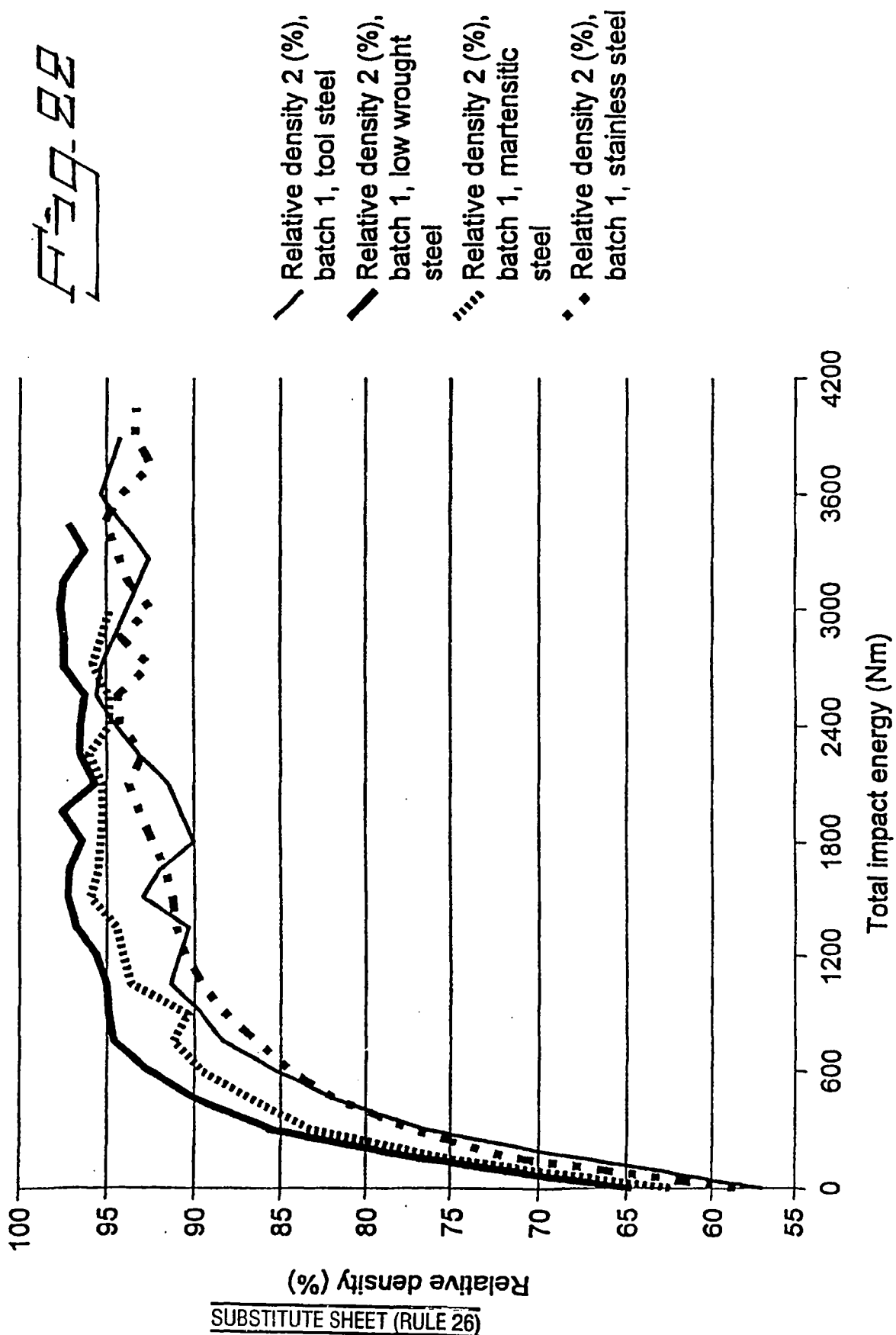


Fig. 21



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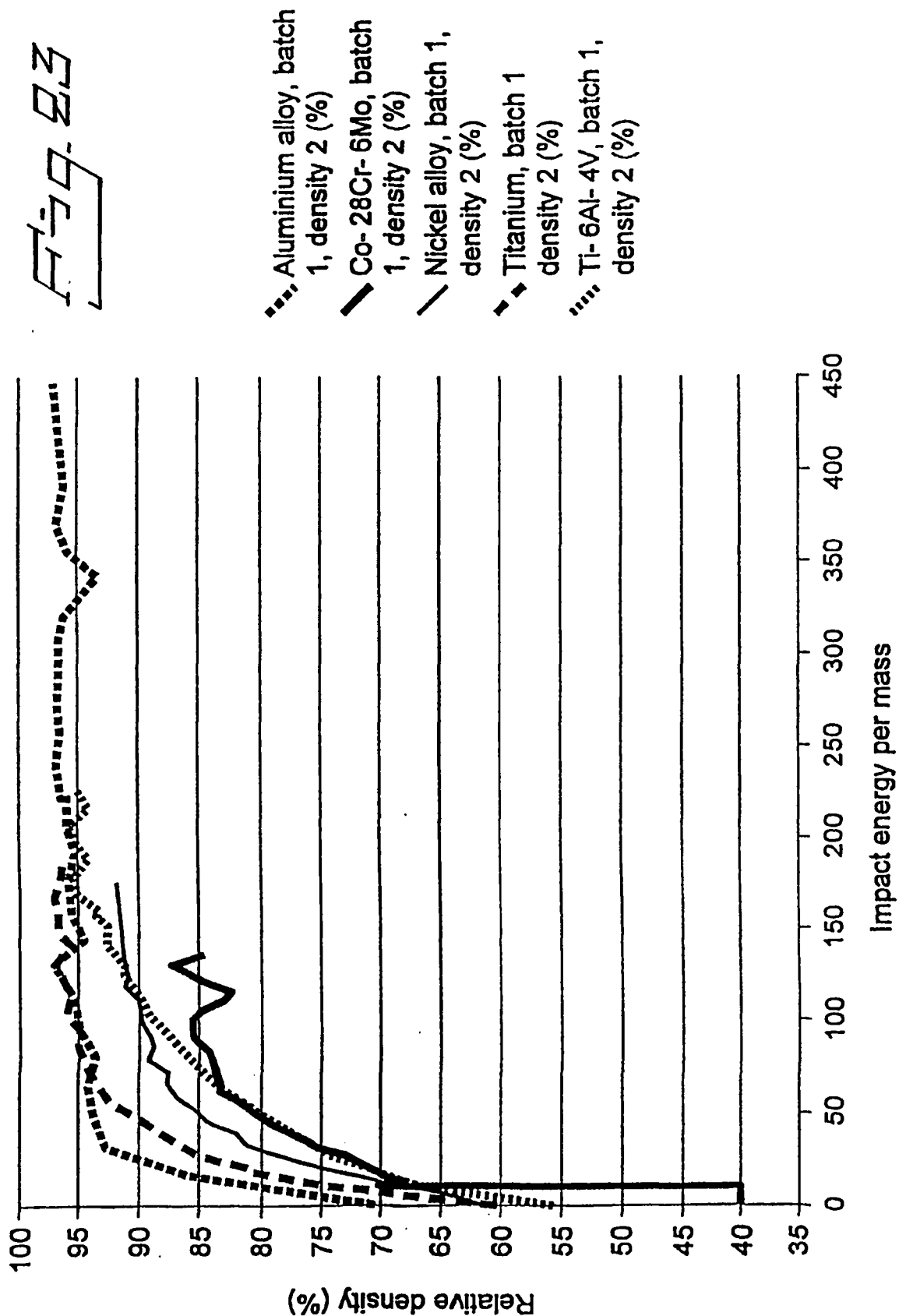
Fig. 22



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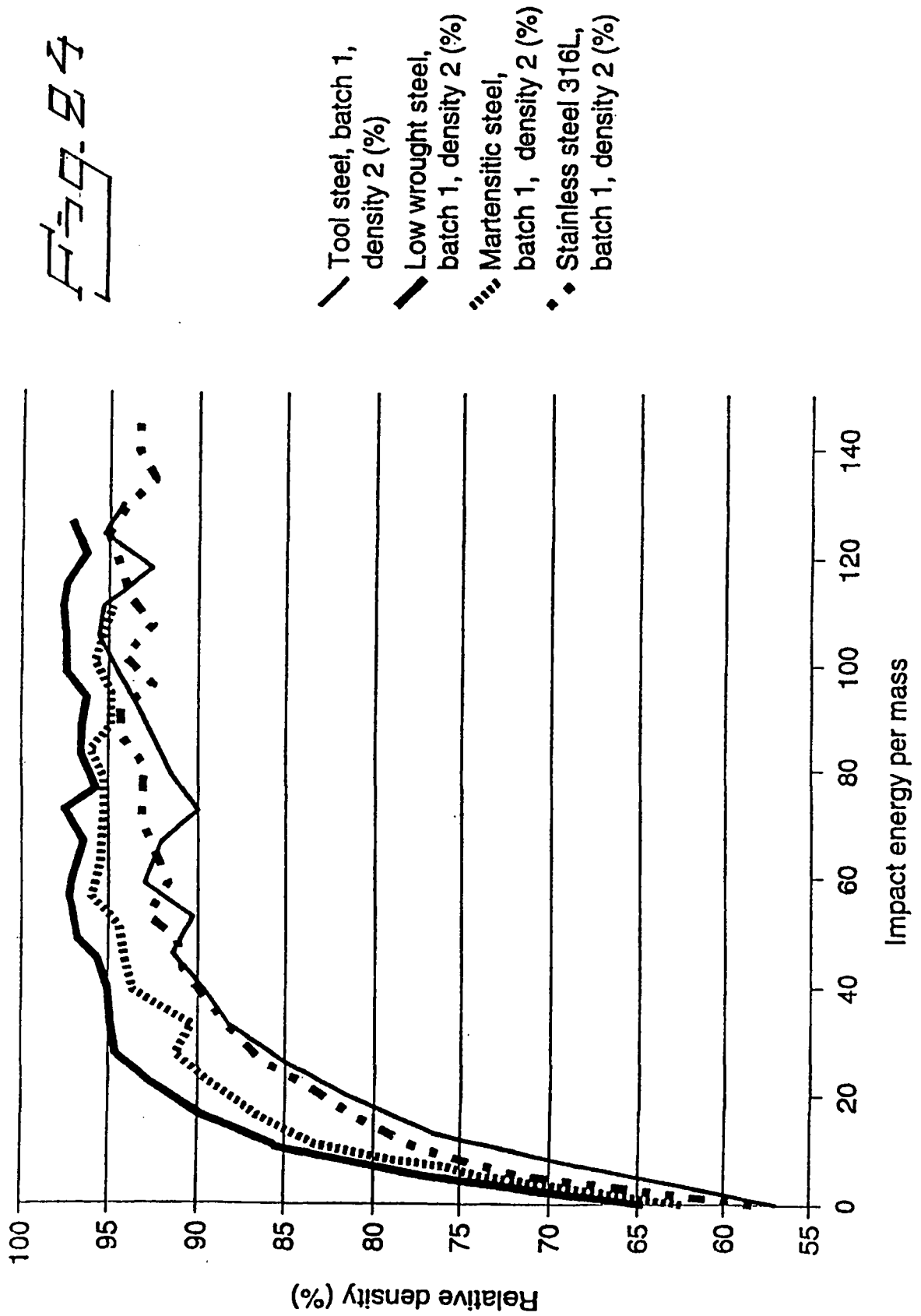
Fig. 23



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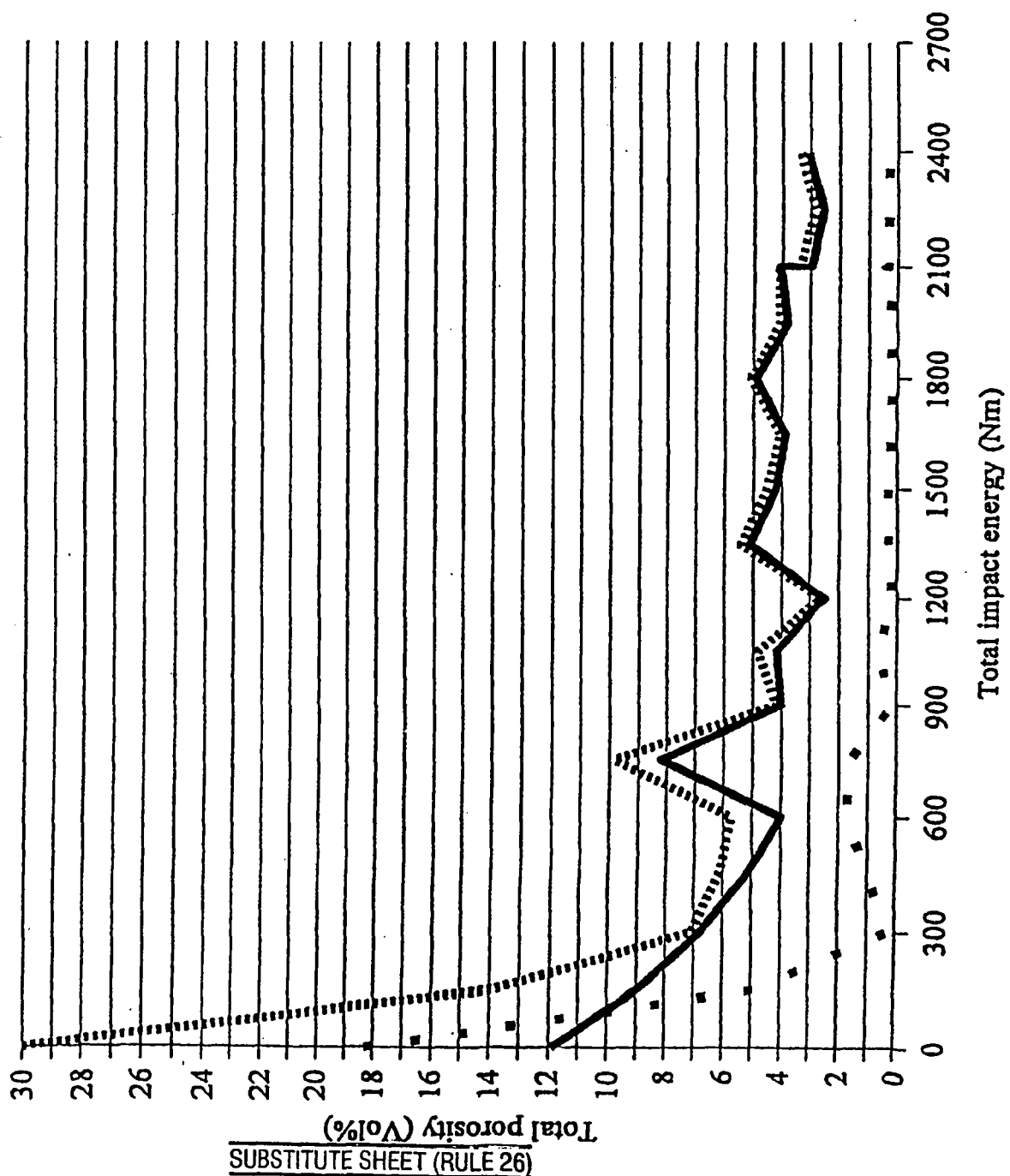
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Fig. 24



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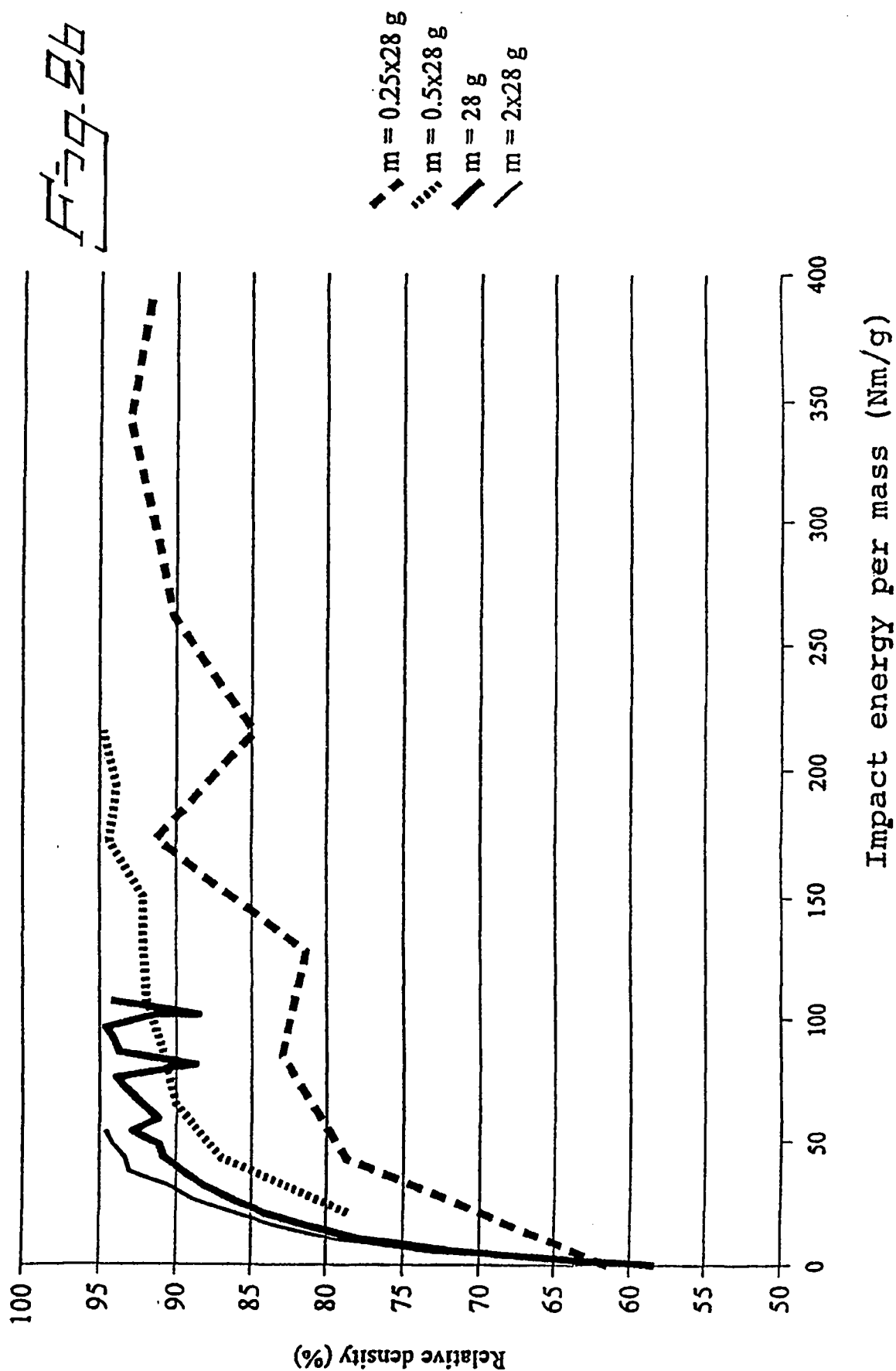
Fig. 25



..... Vol % Total pores
 ♦ Vol% open pores
 — Vol% close pores

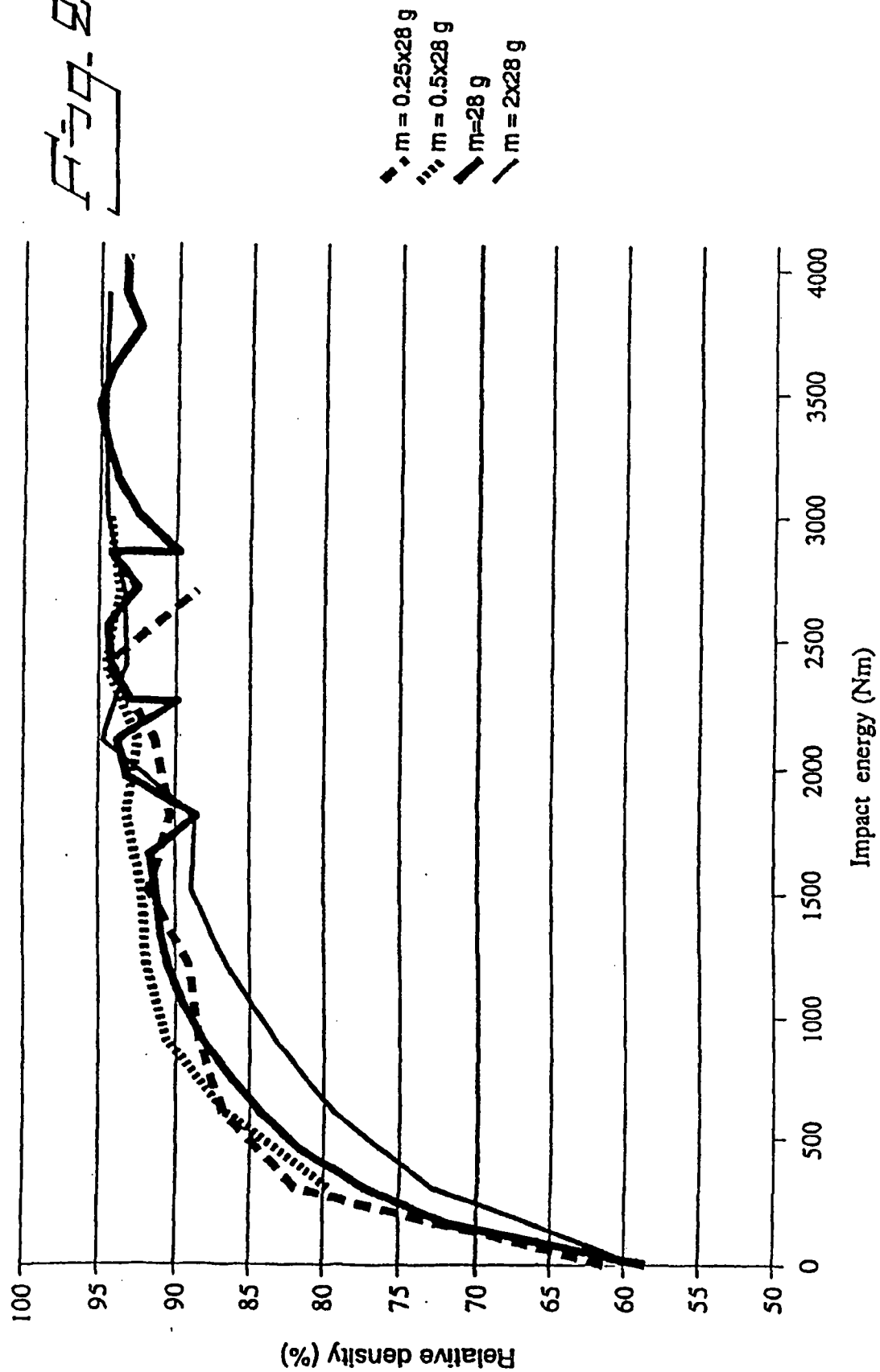
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Fig. 26



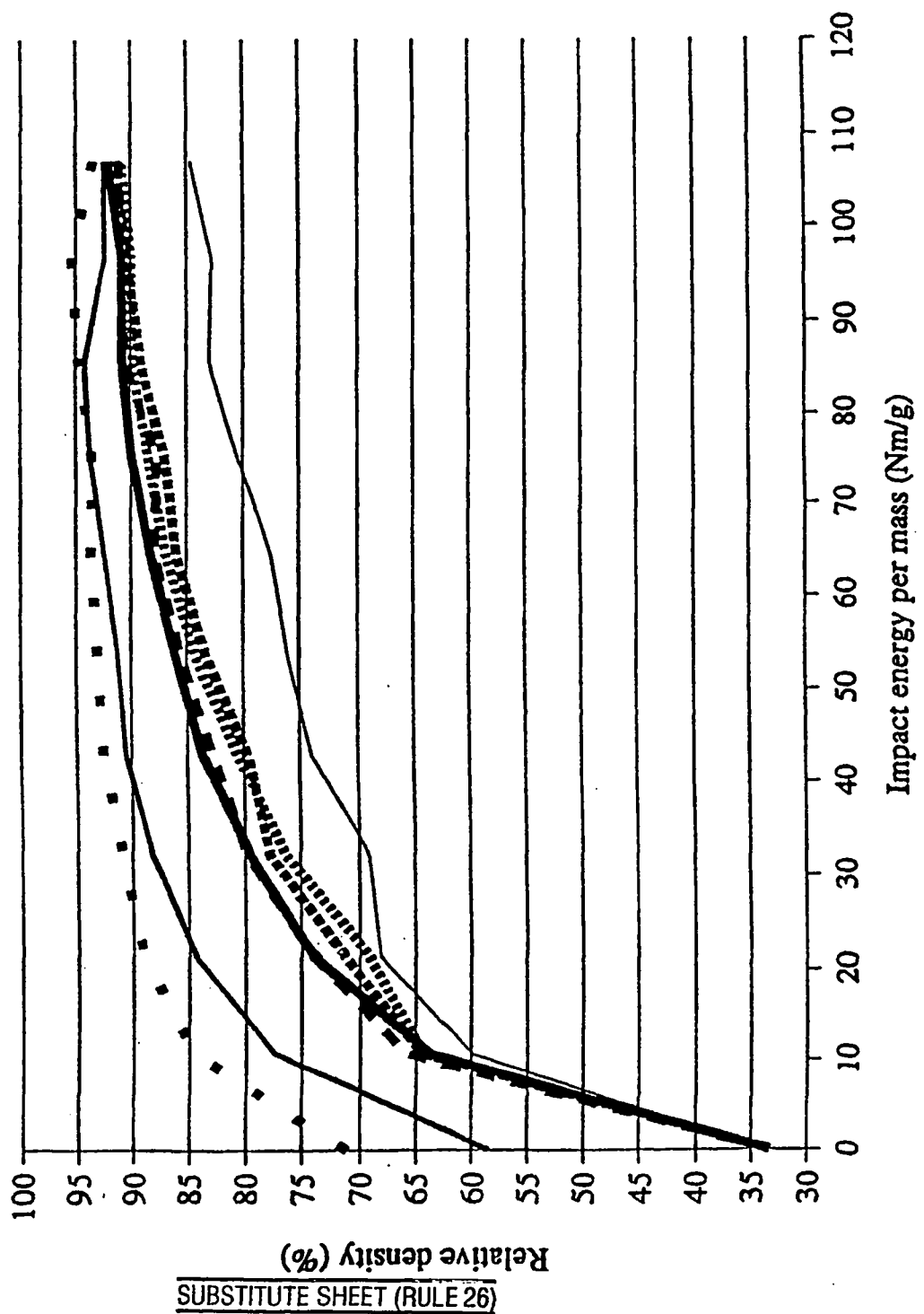
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Fig. 27



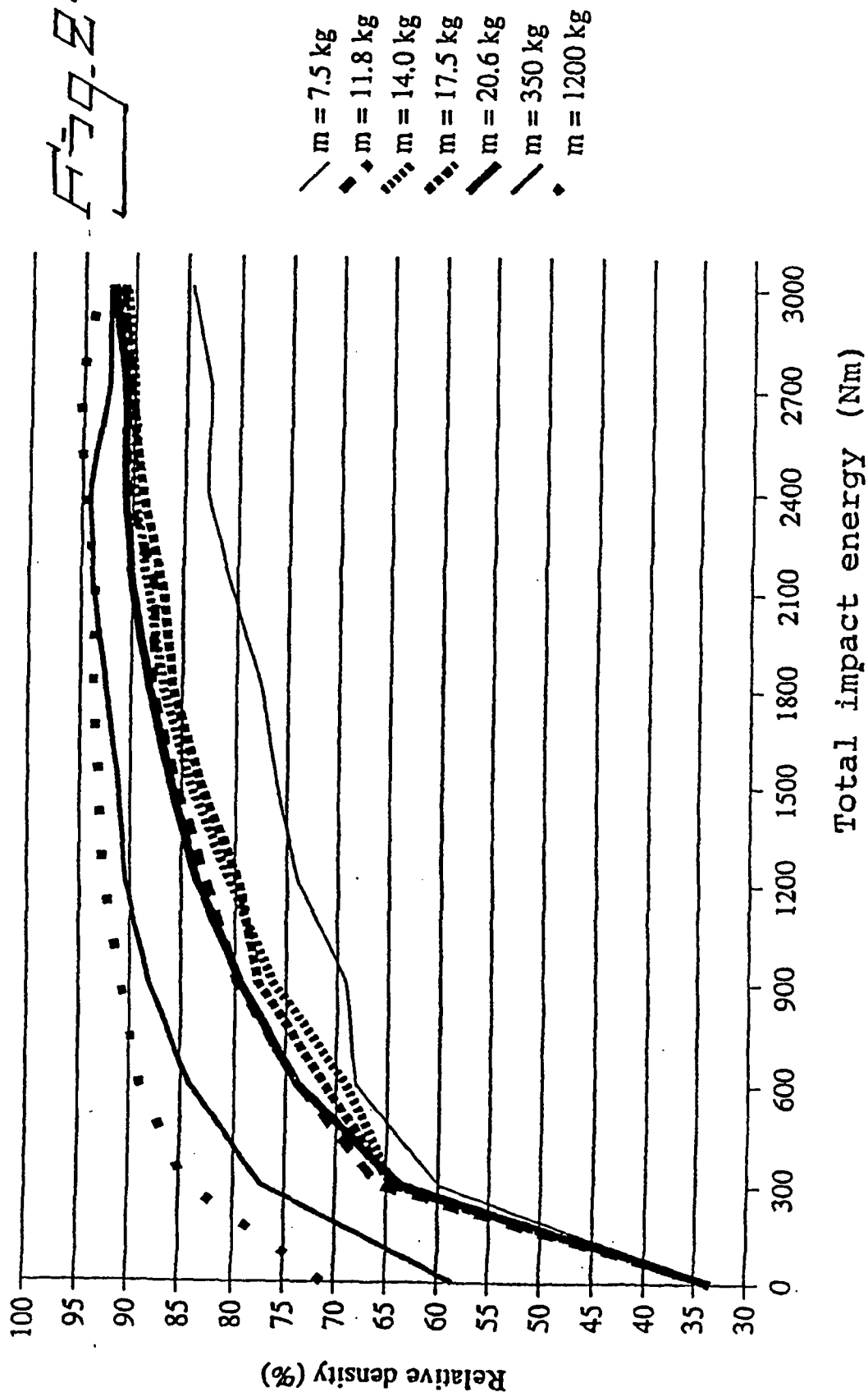
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Fig. 2B



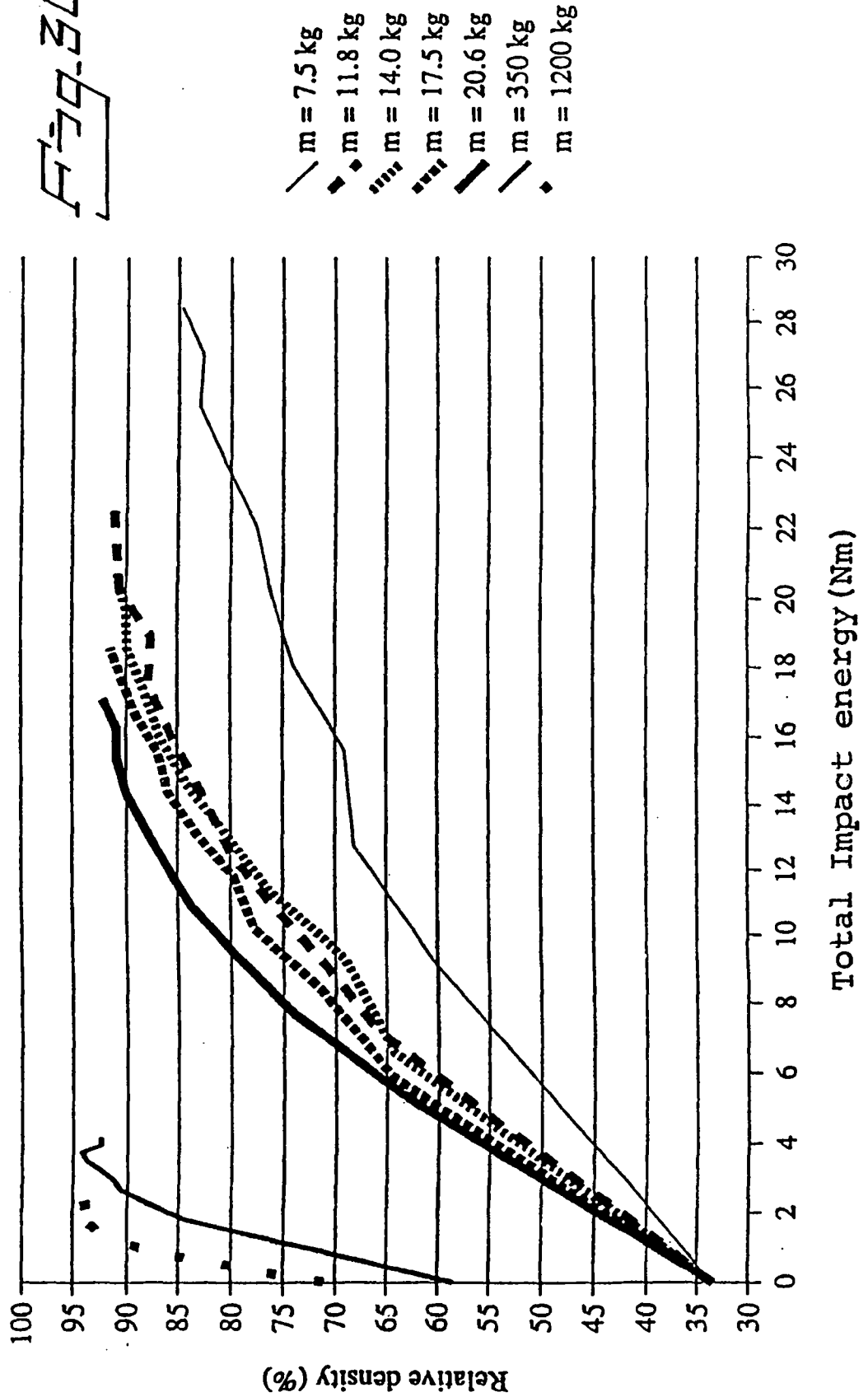
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Fig. 29

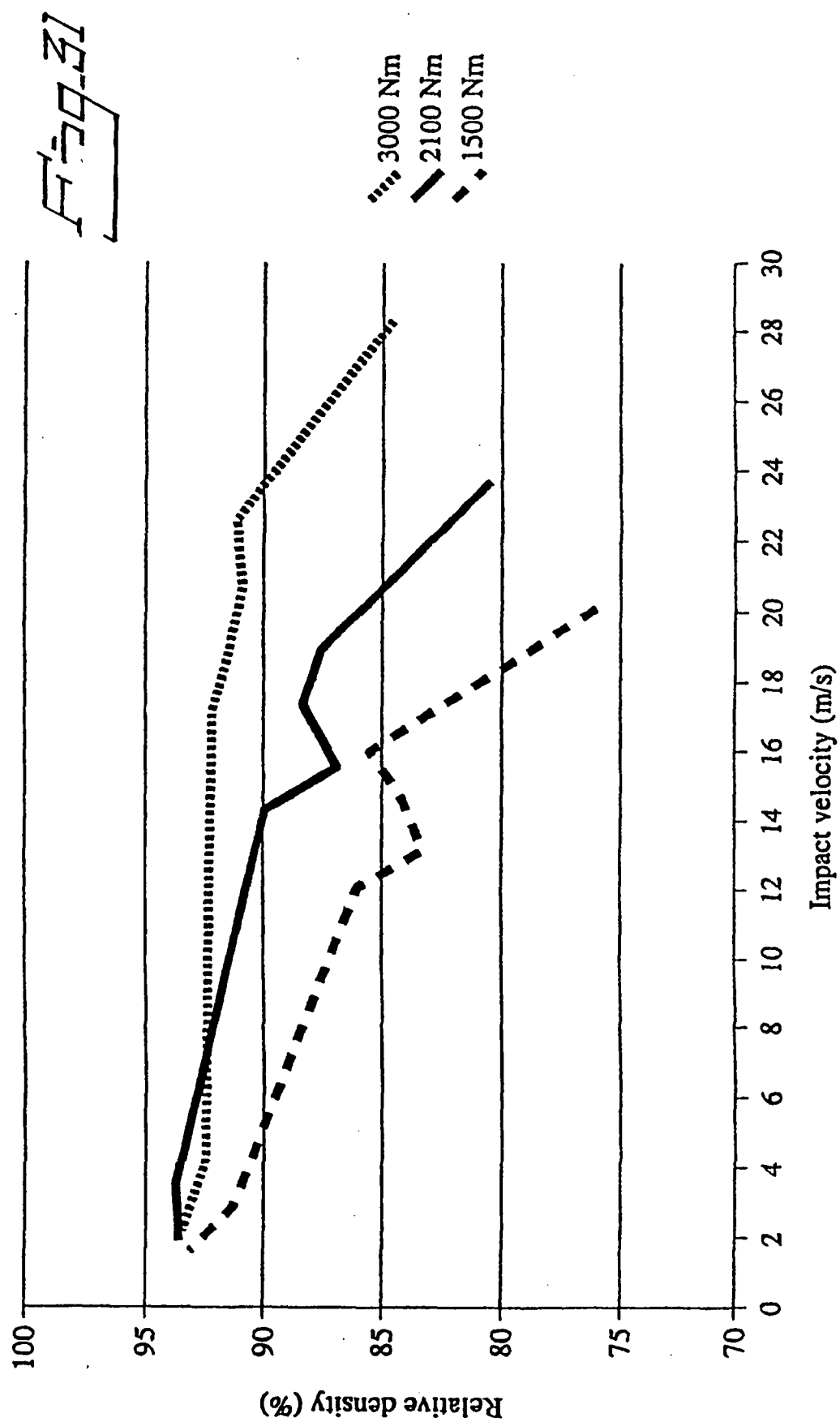


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Fig. 30

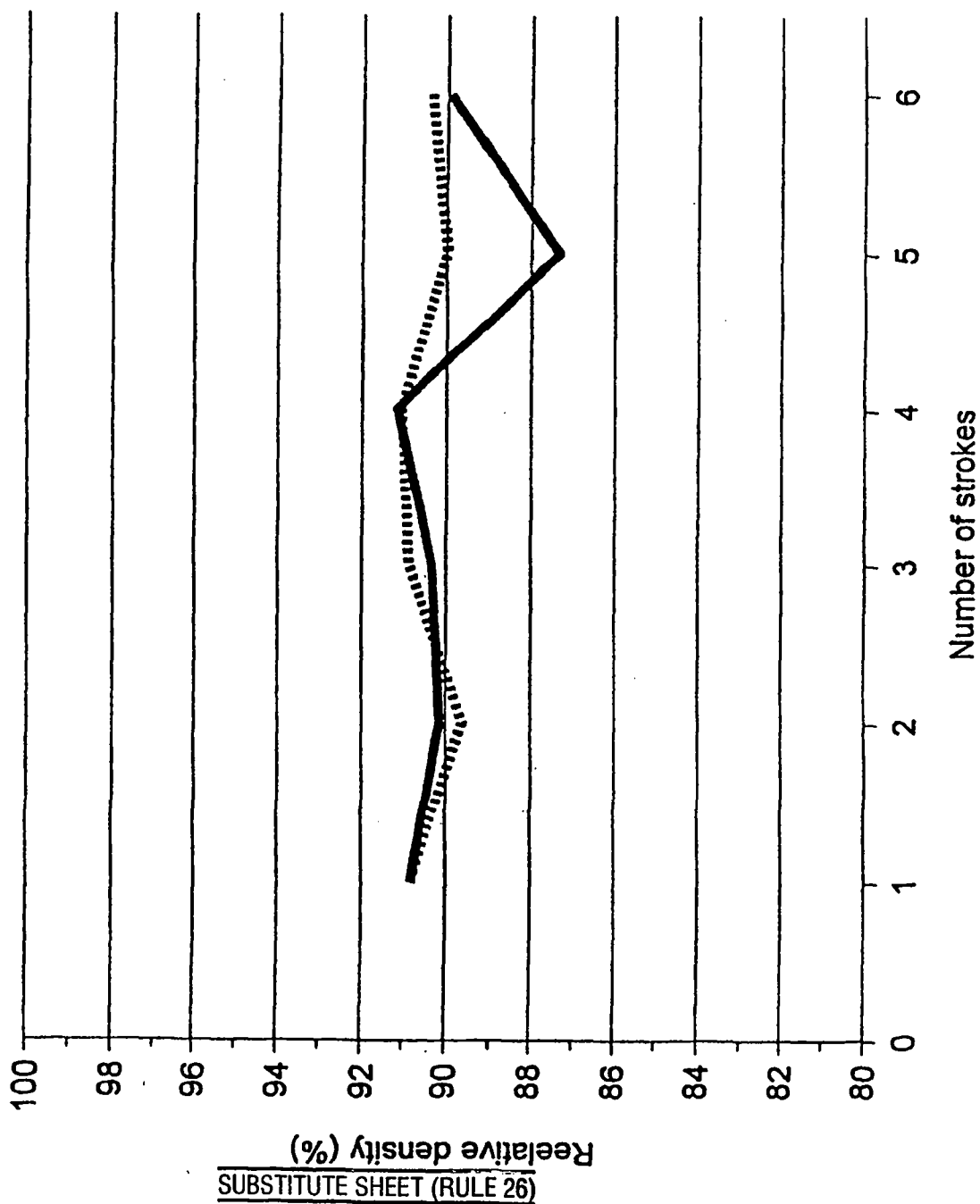


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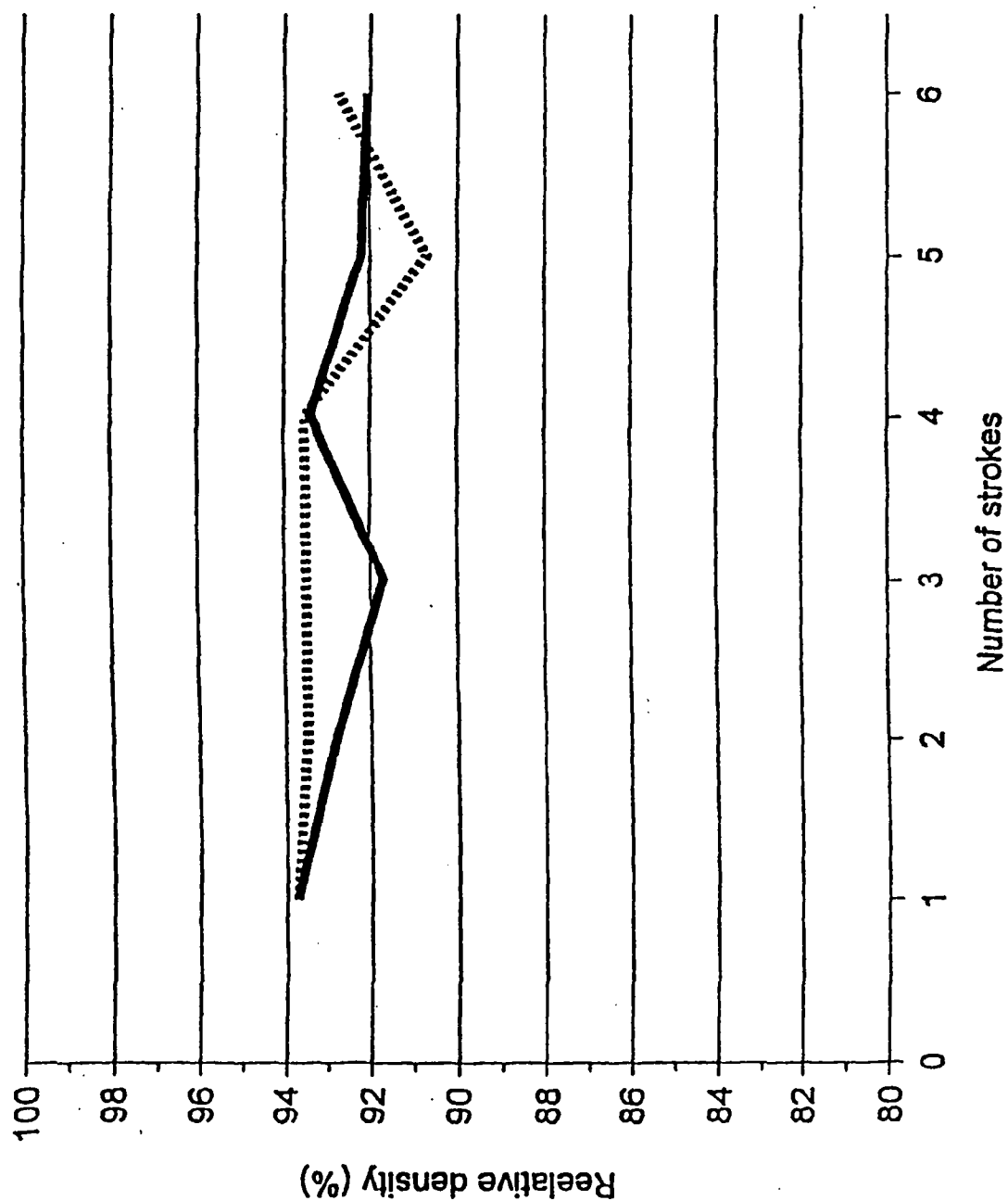
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Fig. 32



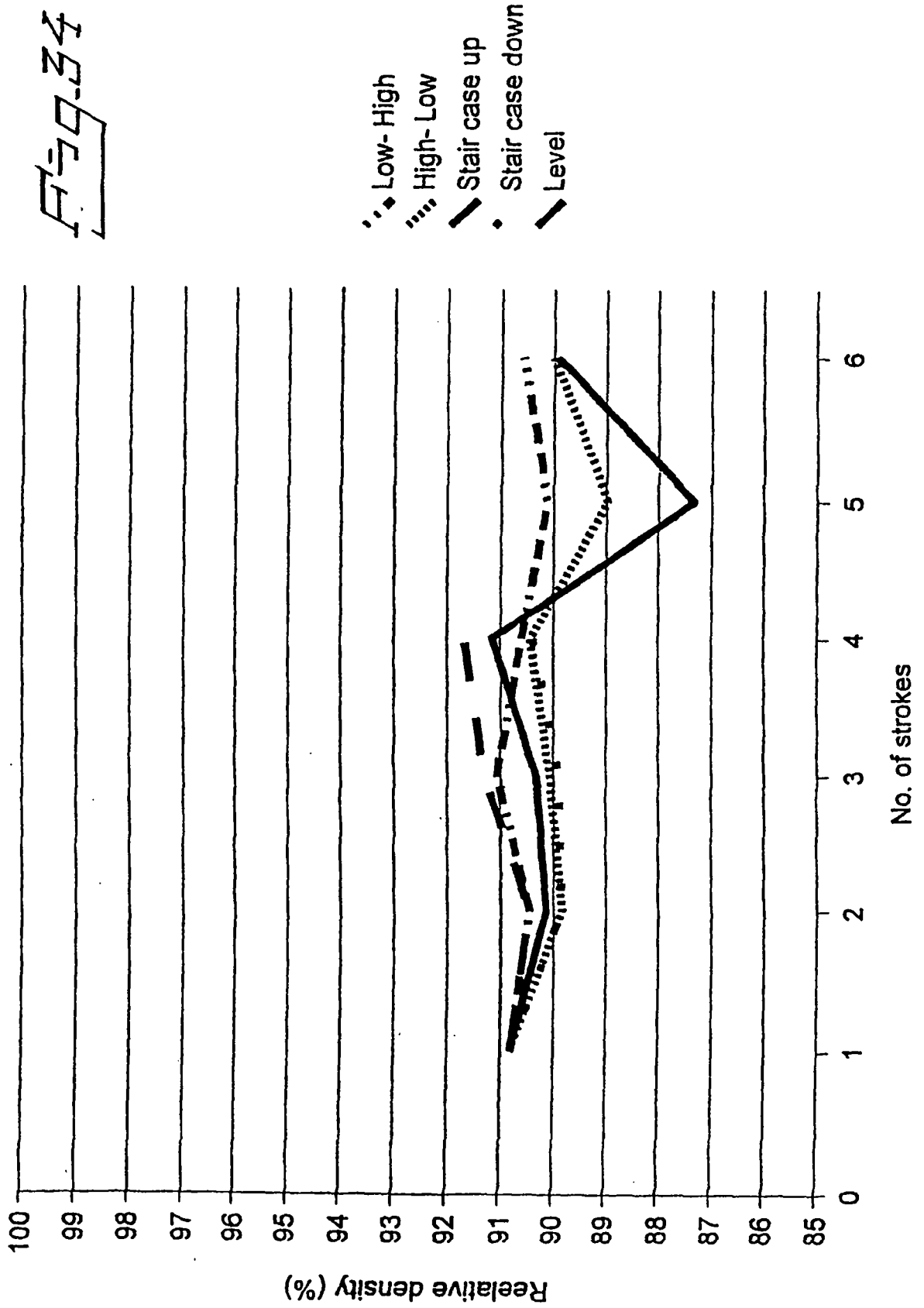
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Fig. 33



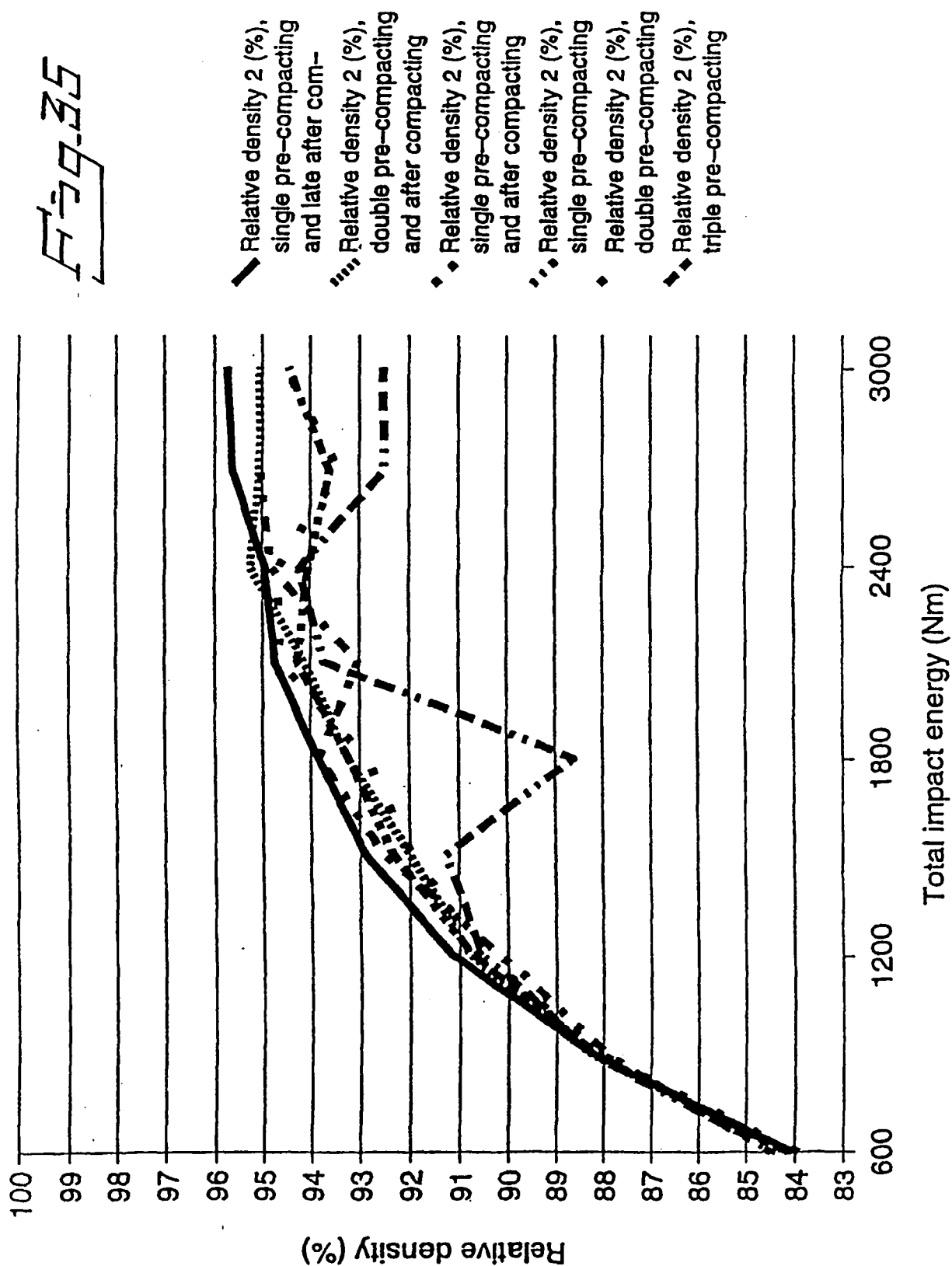
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Fig. 34



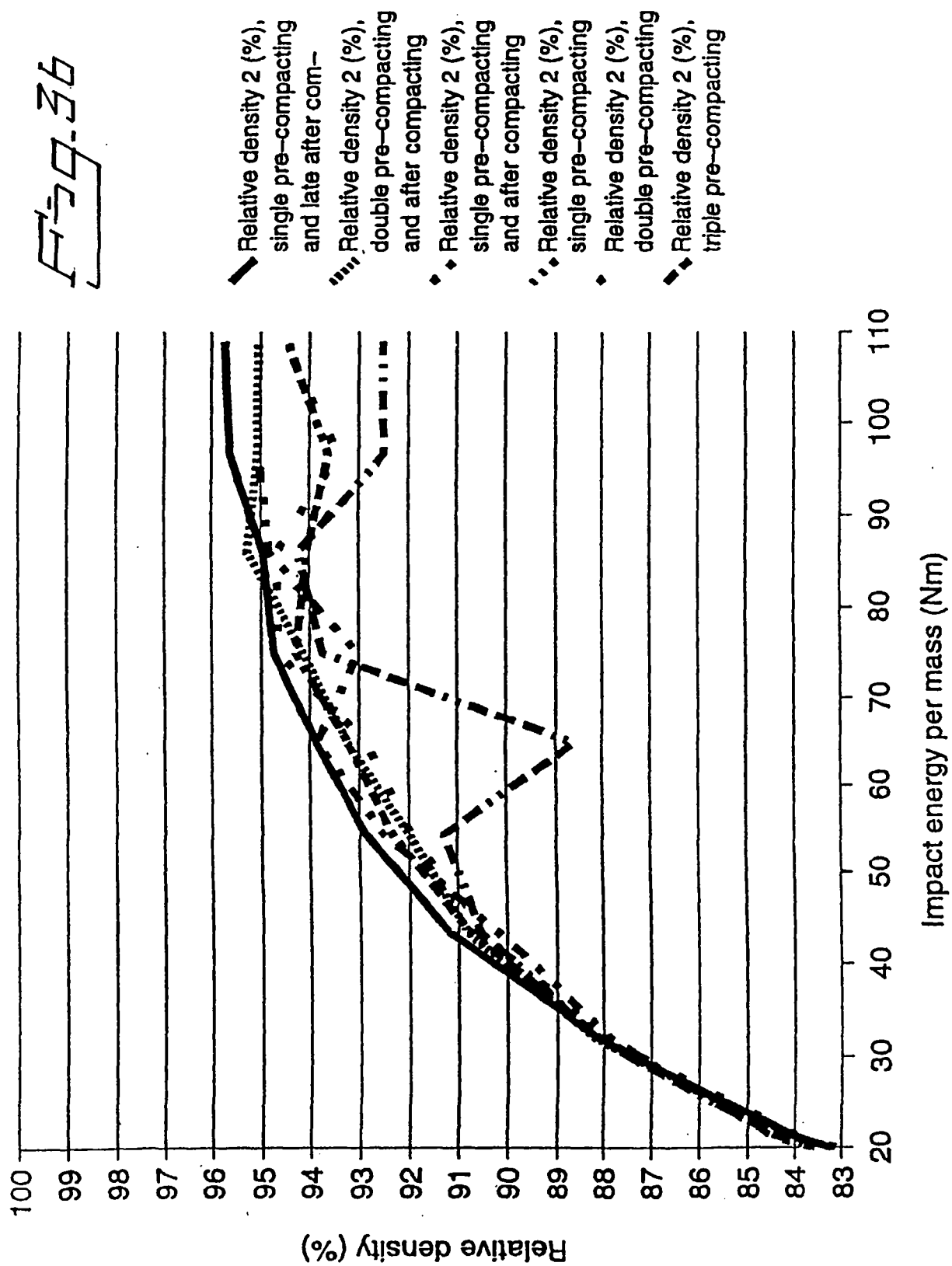
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Fig. 35



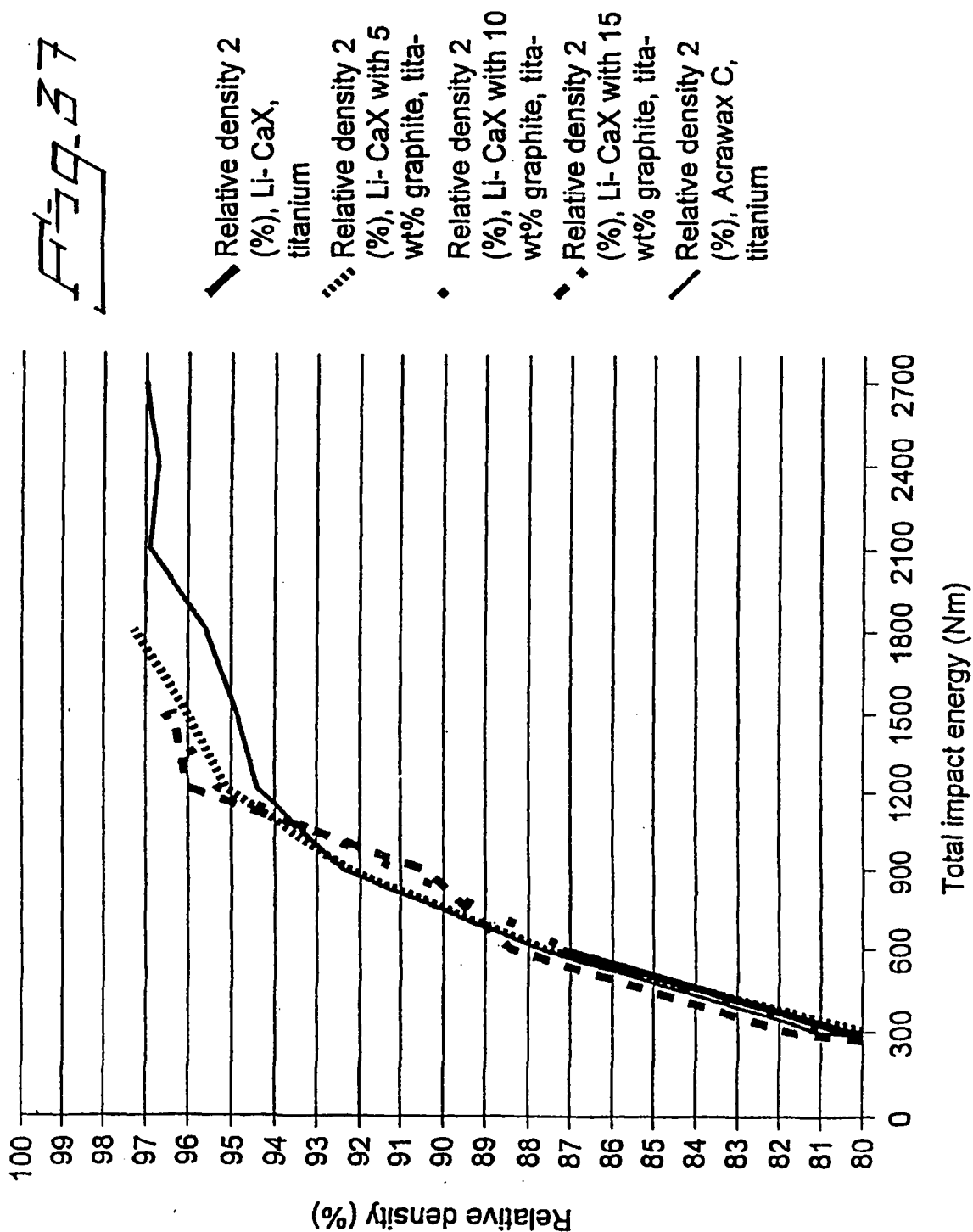
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Fig. 36



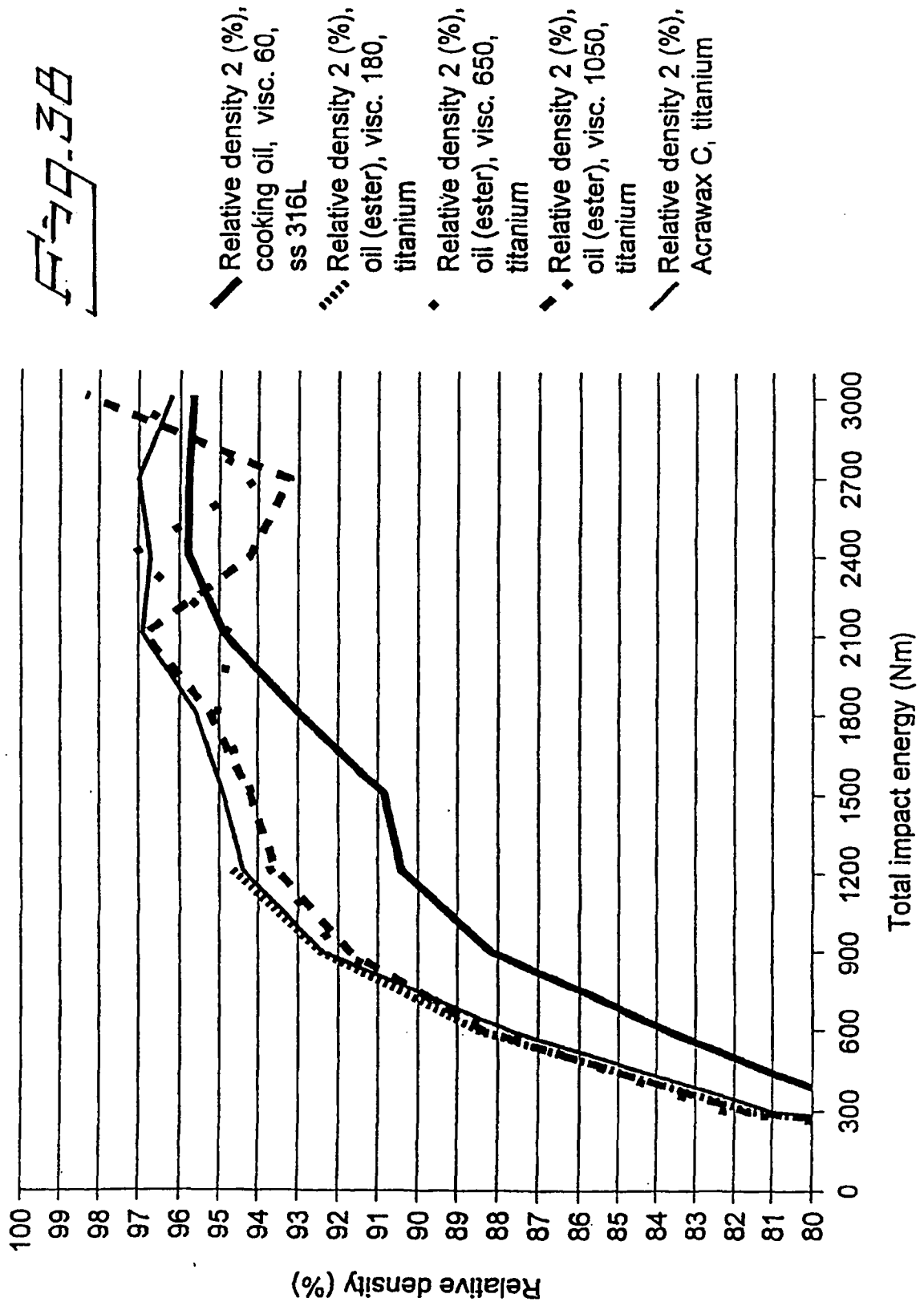
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Fig. 37



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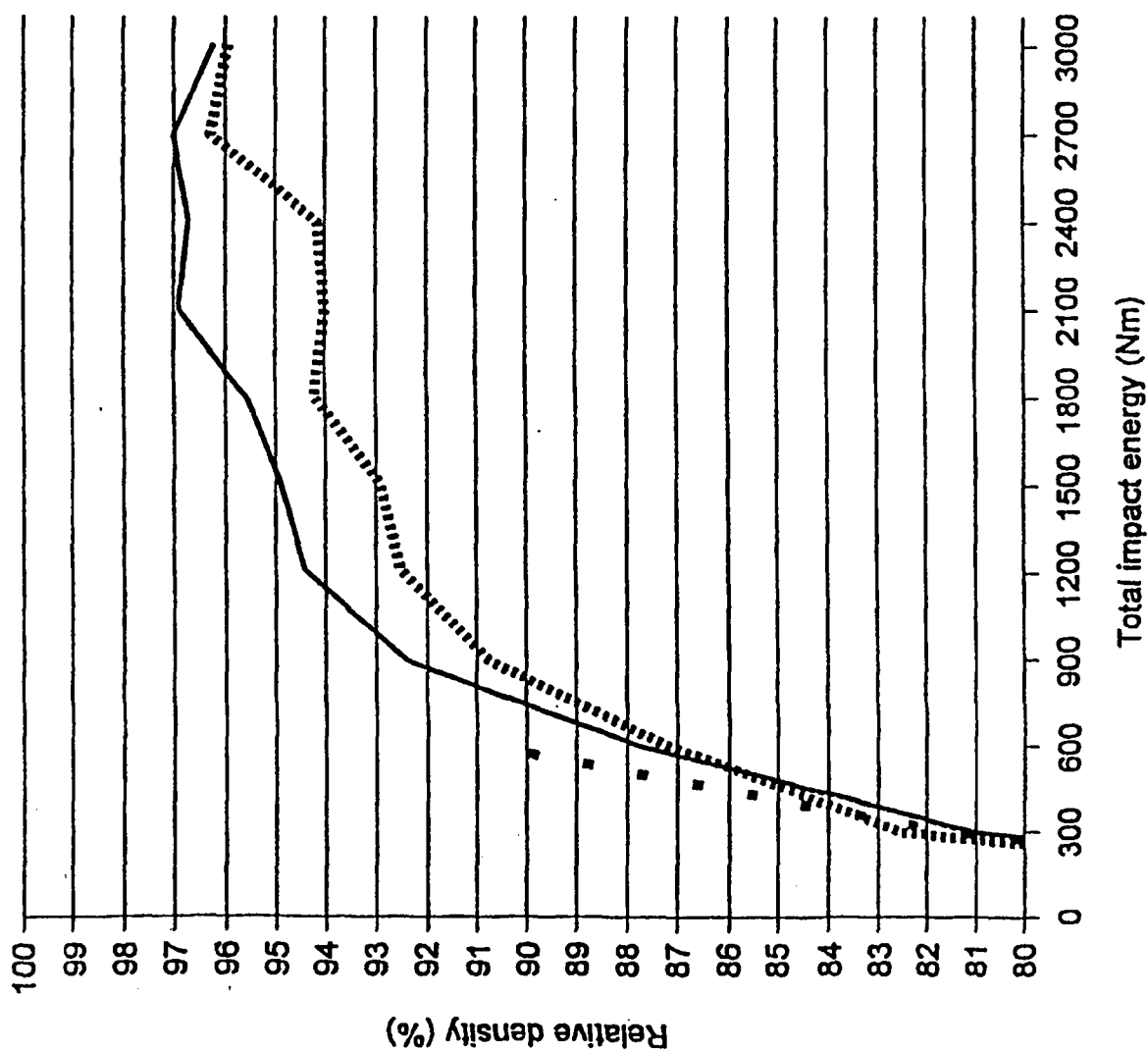
Fig. 3B



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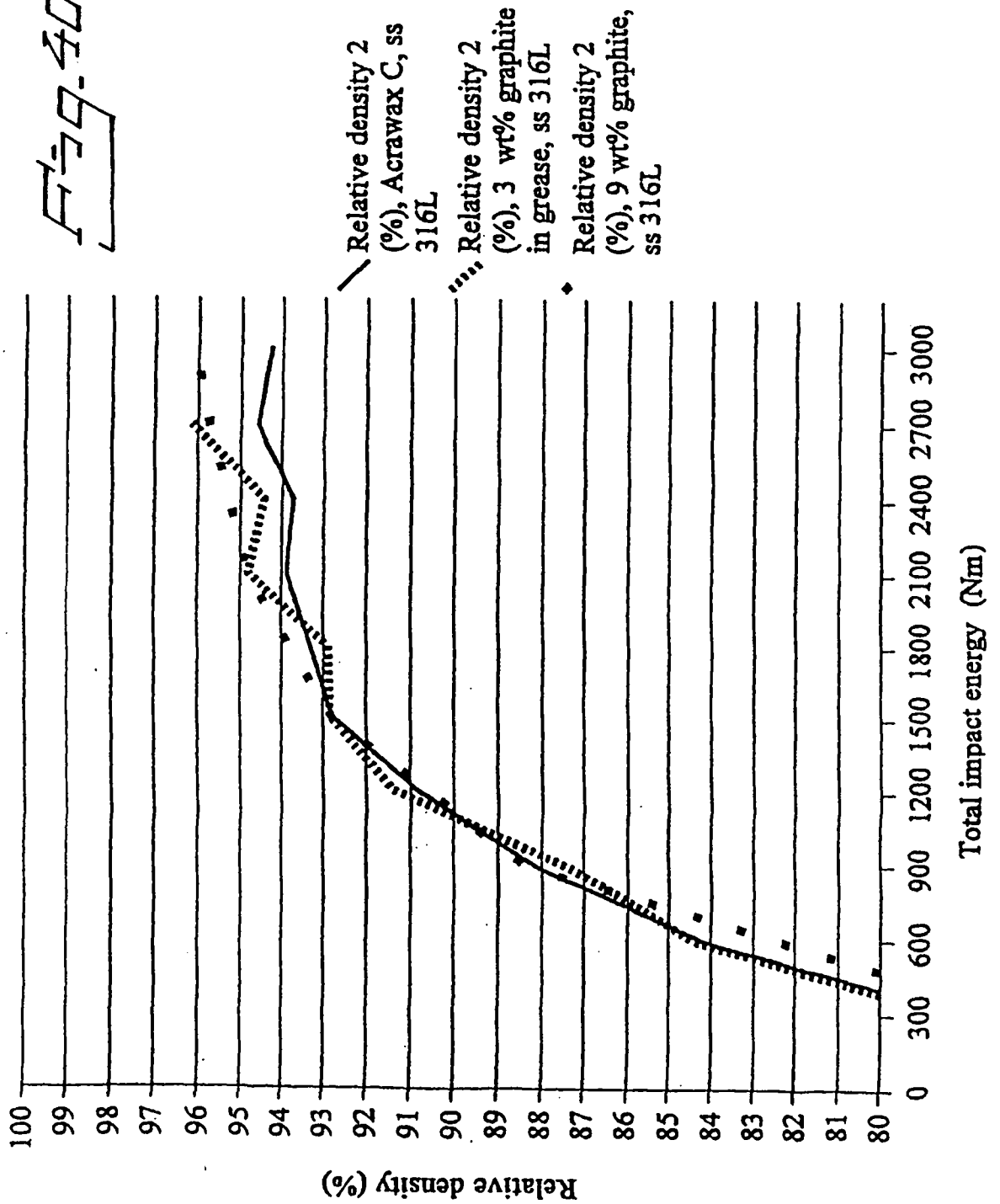
Fig. 39

- ◆ Relative density 2
(%), Teflon spray
- Relative density 2
(%), Teflon grease
- Relative density 2
(%), Acrawax C,
titanium



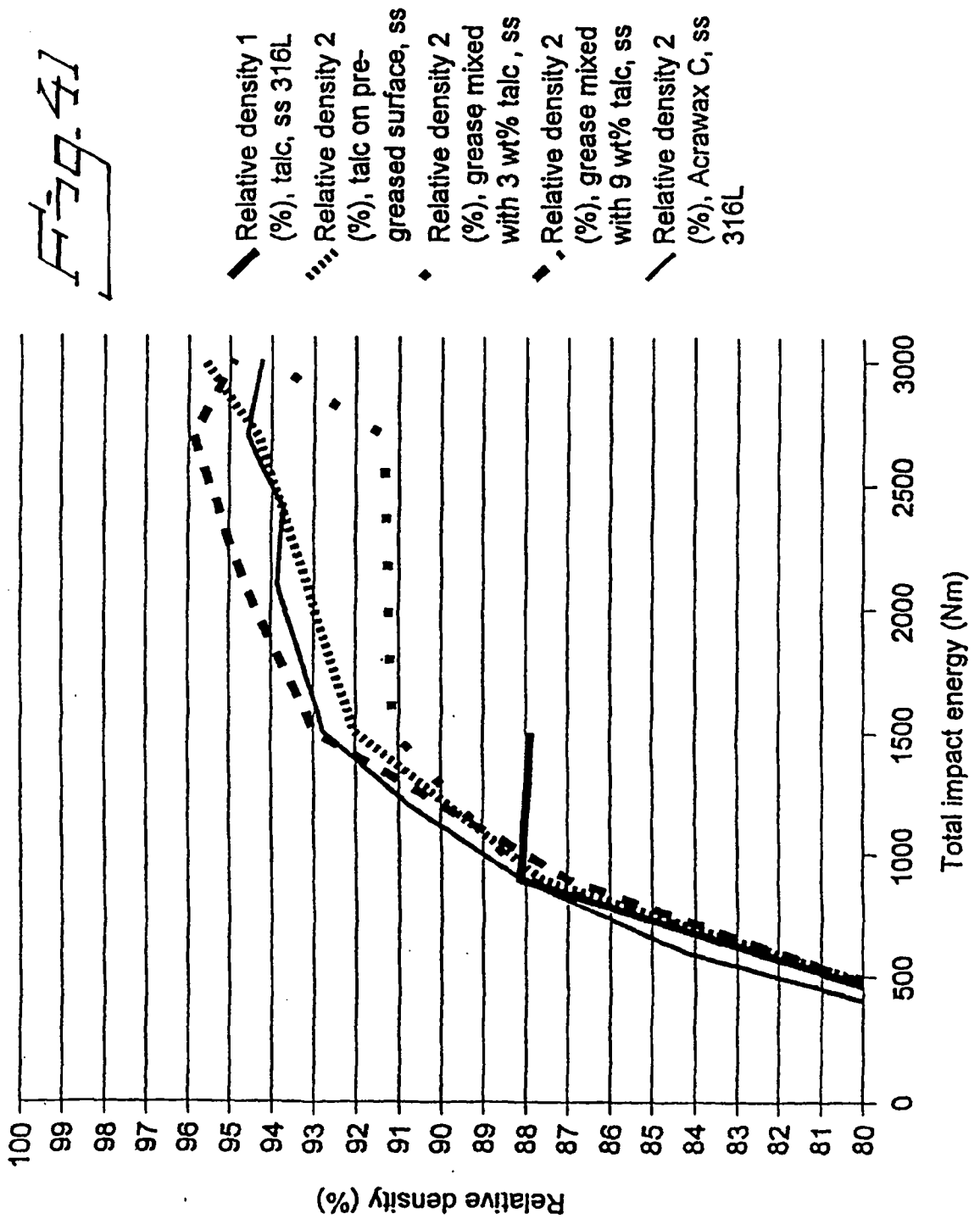
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Fig. 40



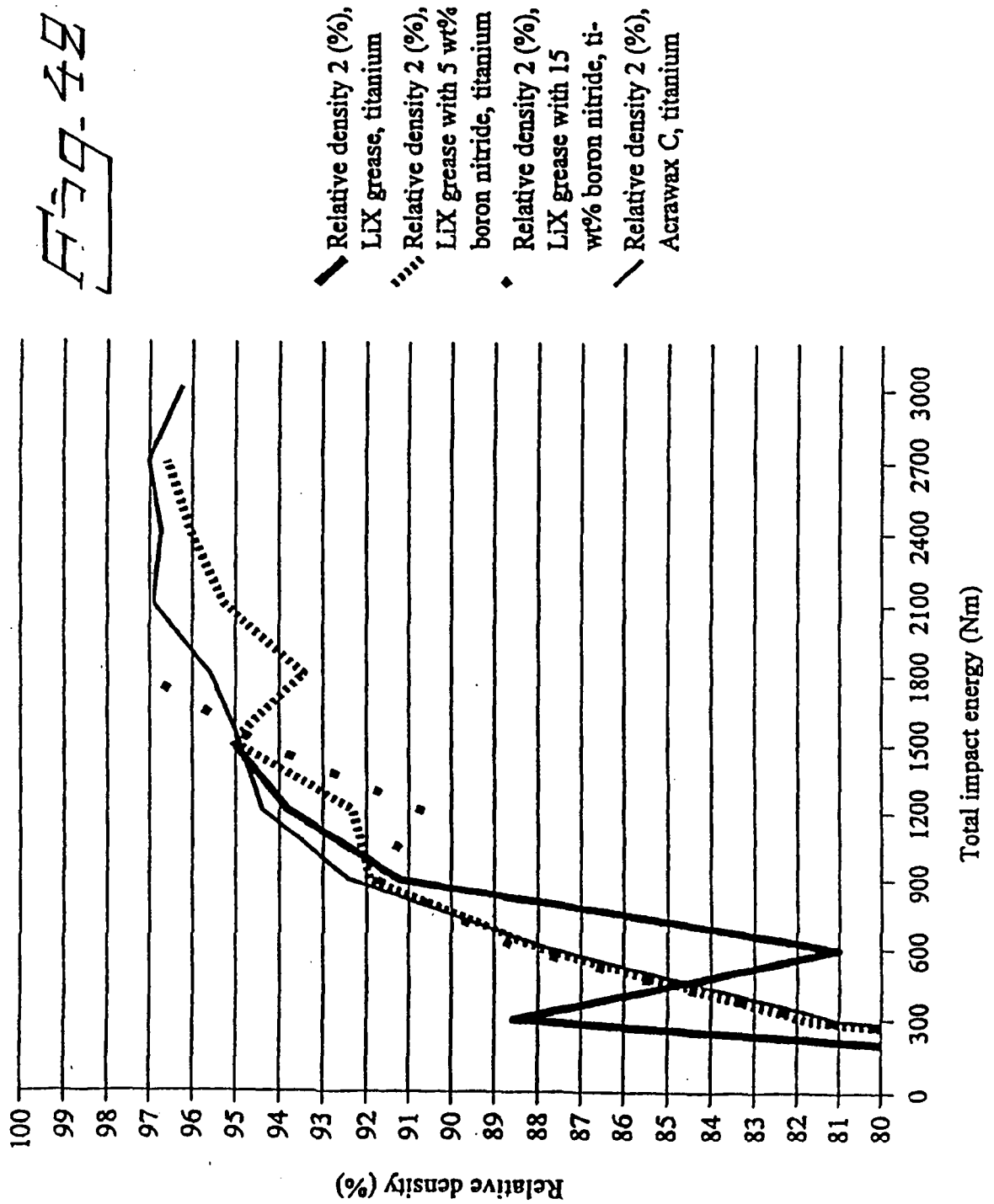
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Fig. 41



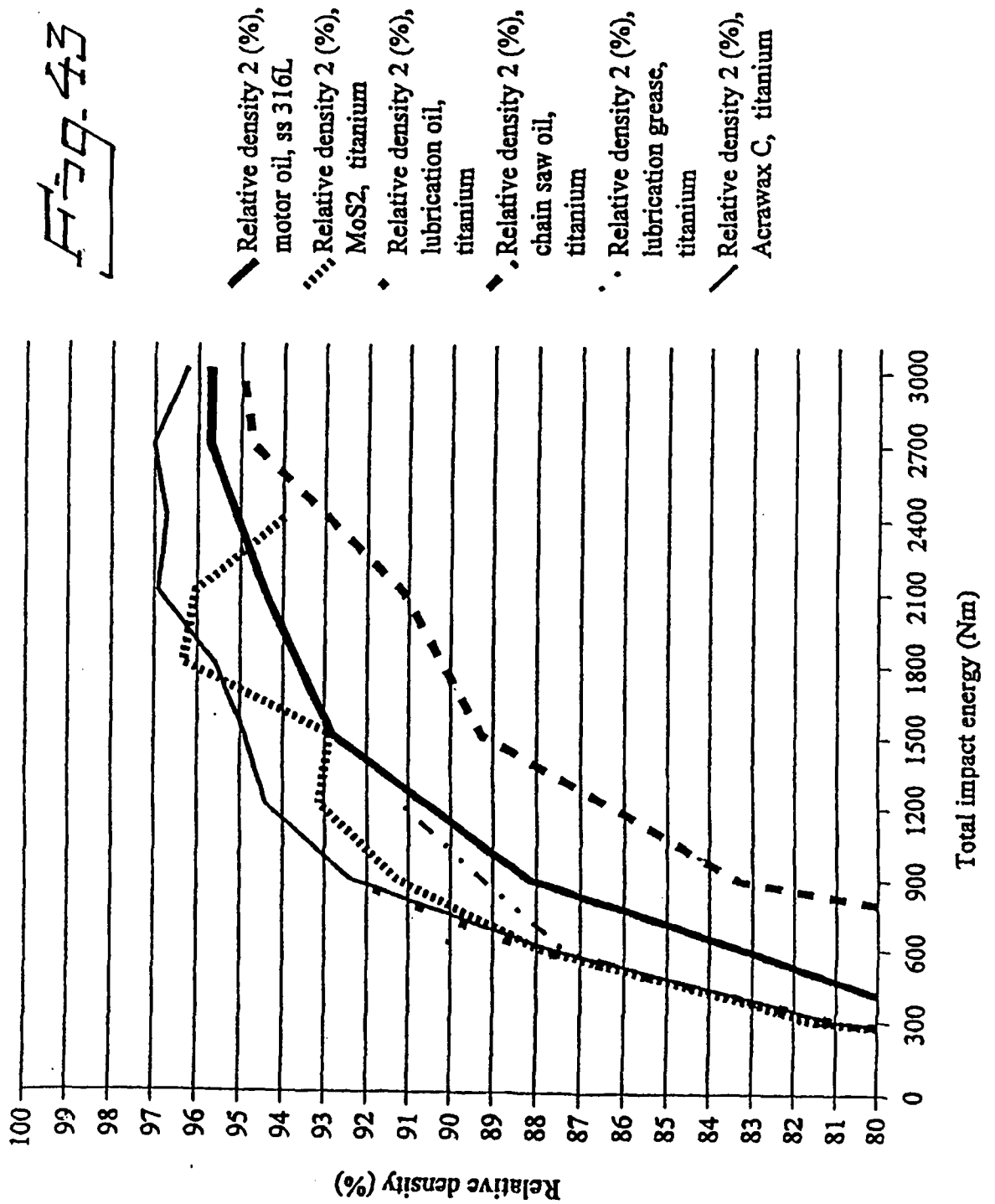
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Fig. 42



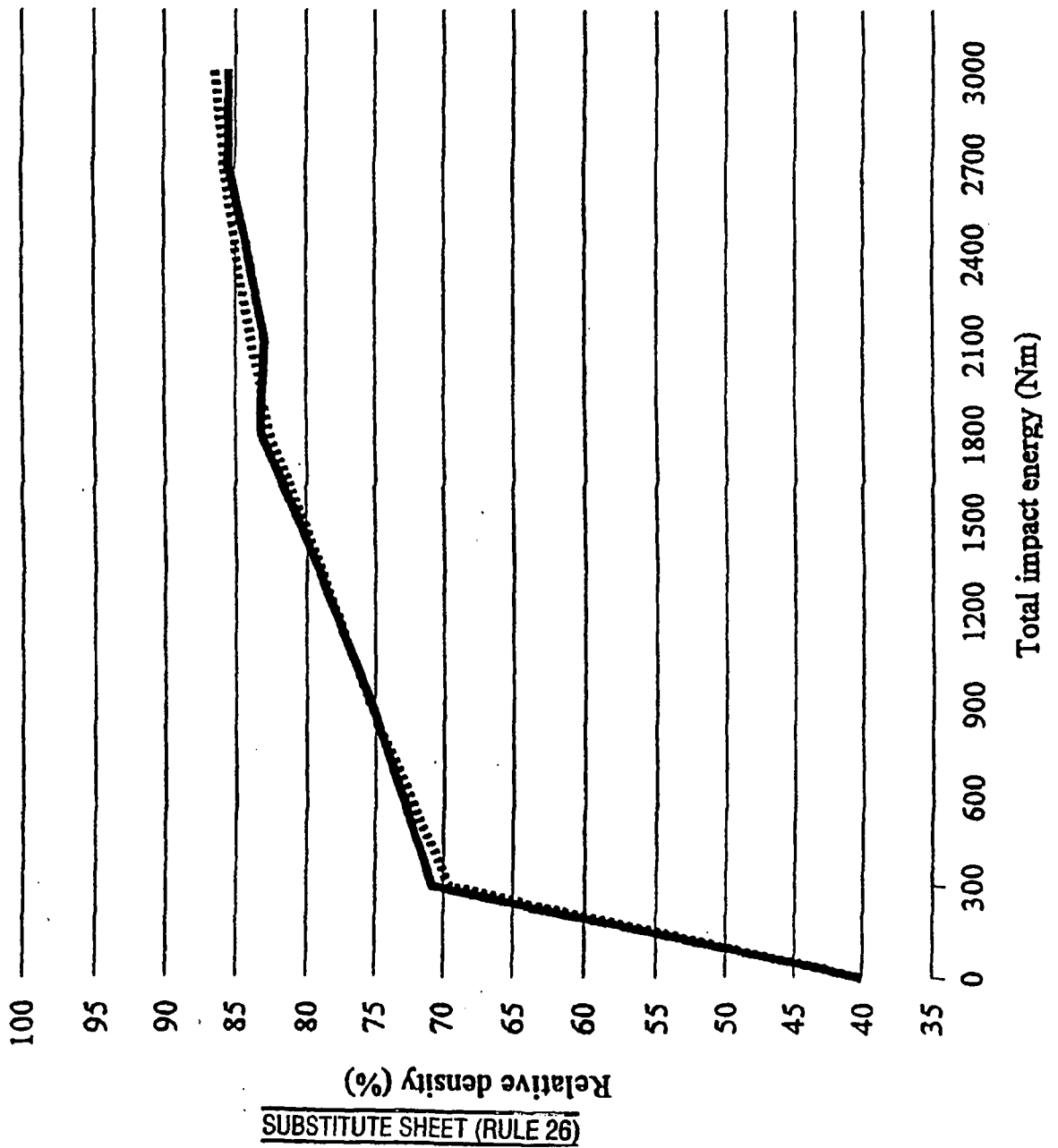
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Fig. 43



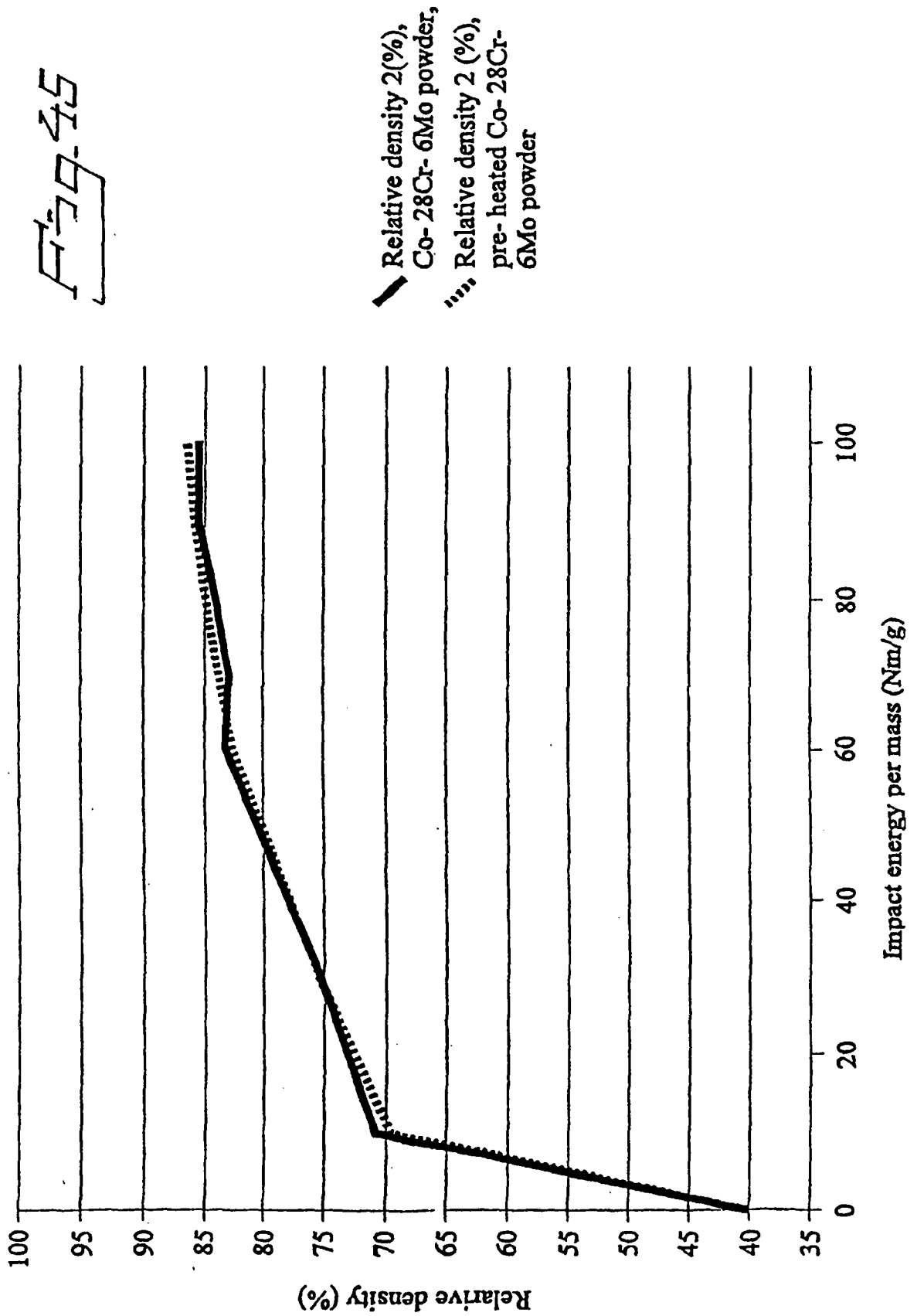
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Fig. 44



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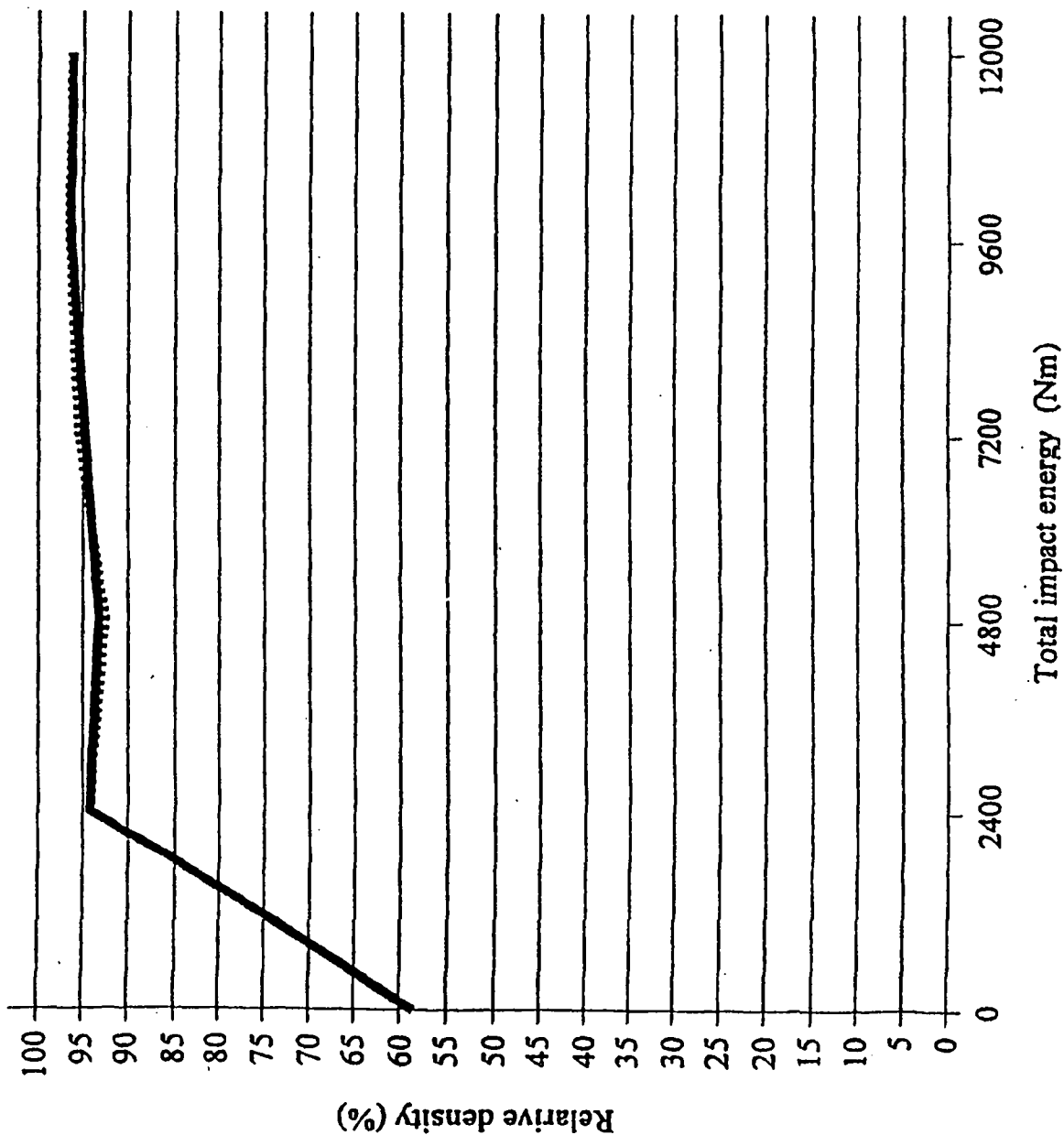
Fig. 45



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Fig. 4b

— 2400 Nm per stroke, 0.4 s
 2400 Nm per stroke, 0.8 s



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Fig. 47

