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(54) **Title:** A METHOD FOR FORMING SHEET MATERIAL COMPONENTS

(57) **Abstract:** A method for forming a component from a Ti-alloy or Ni-alloy sheet material. The method comprising heat treating the sheet material, wherein a final temperature of the sheet material is above 100°C below a β -transus temperature of the sheet material. The sheet material is formed into a predefined configuration between two dies. Forming is completed before the temperature of the sheet material reaches a start temperature for β to martensite transformation within the sheet material and wherein the temperature of the dies is less than a finish temperature for β to martensite transformation within the sheet material.



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A Method for Forming Sheet Material Components

Field

- 5 The present disclosure relates to methods for forming sheet material components. In particular, but not exclusively, the disclosure relates to method for forming components from titanium alloy sheets.

Background

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High performance lightweight materials are desirable in many industries. For example, the transport industry looks to such materials both to improve performance and reduce fuel consumption. For at least these reasons, titanium (Ti)-alloys, which are high temperature lightweight metals, have been widely used in aerospace. Due to their
15 superior strength-to-weight ratio, the application of Ti-alloys has great potential to reduce CO₂ emission and fuel consumption.

20

Forming complex shapes from Ti-alloys is technically challenging, however. In particular, the difficulties in forming complex structures from single sheets of Ti-alloy have historically
favoured fabrication processes in which multiple sheets are joined to one another to form the complete component. However, the joins themselves are complex to carry out and offer potential failure points, while a component formed of multiple parts inherently adds to the overall part count and thus the cost of the system.

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One technique used for forming Ti-alloy sheets into desired shapes is isothermal hot forming (IF). In this process, the Ti-alloy sheet is formed at elevated temperatures using two dies brought together to shape the sheet into a desired configuration. The use of high temperature improves the formability of the sheet and significantly reduces the required forming load. This results in much reduced springback effects in comparison to attempts
30 to form at cold temperatures due to small residual stress.

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In isothermal hot forming processes, the dies used to form the sheet into the desired configuration are maintained at the same temperature as the sheet material itself. For example, they may be heated together with the sheet in a furnace. As such, these
processes require heat resistant dies and incur cost/inefficiency in the requirement to heat these dies. Moreover, the forming operation can take a significant time to complete, both in the process of bringing the dies together to shape the sheet material and in the

requirement to cool the material subsequently (which often occurs within the dies to avoid later deformations). In addition, there is the possibility of having to pickle the part (clean the surface chemically) after forming if there is any α -case or oxygen enrichment of the surface.

5

An alternative approach has been suggested to overcome some of these difficulties. This is known as superplastic forming (SPF). In this process the sheet is deformed into a single die cavity by applying gas pressure at a predetermined rate to keep a constant strain rate, enabling the formation of very complex shapes in a single operation without
10 springback by requiring very low gas pressure (0.2 MPa). However, there are still limitations: heat resistant tool materials are still required; expensive equipment that can provide high temperatures and tonnage to balance forming pressure is necessary; long preheat times are necessary to reach the forming temperature; and a protective atmosphere, such as argon, is usually needed to prevent surface oxidation. Furthermore,
15 SPF techniques are typically very low in productivity, and consequently energy-efficiency, due to slow strain rate, which is normally 10^{-4} /s for SPF of Ti-6Al-4V (the most widely used Ti-alloys accounting for 60% of total Titanium production).

There remains a need for an improved process of forming components from Ti-alloy
20 sheets and other materials of similar properties. Similar issues arise for Nickel based alloys.

Summary

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According to an aspect of the disclosure, there is provided a method for forming a component from a Ti-alloy or Ni-alloy sheet material, comprising:

heat treating the sheet material, wherein a final temperature of the sheet material is above 100°C below a β -transus temperature of the sheet material;

30

forming the sheet material into a predefined configuration between two dies, wherein forming is completed before the temperature of the sheet material reaches a start temperature for β to martensite transformation within the sheet material and wherein the temperature of the dies is less than a finish temperature for β to martensite transformation within the sheet material.

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By ensuring that the forming step is carried out within a required time frame and that the temperature of the material is sufficiently high during heating, relatively cold dies can be

used during the forming step. This can greatly reduce the cost and time required for the process in comparison with some conventional techniques. In particular, it is not necessary to heat the dies to match the temperature of the sheet material, meaning that energy does not have to be expended in this way. The final temperature of the sheet material at the end of the step of heat treating the sheet material is above 100°C below the β -transus temperature, or preferably above 10°C below the β -transus temperature. The final temperature may be above the β -transus temperature. Preferably, the final temperature is below the melting point of the material. In some preferred embodiments, the final temperature lies within a range having a lower bound of 100°C or 10°C below the β -transus temperature and an upper bound of 100°C or 10°C above the β -transus temperature.

The improved control offered by the proposed process can allow complex-shaped Ti-alloy/Ni-alloy panels to be formed in one operation with high quality with less localised thinning (by taking advantages of materials drawn-in and strain hardening) and ideal microstructural control (through adjustable heat treatment conditions and cooling rates).

The method of this aspect can provide a fast forming process. This can reduce the deterioration of post-form mechanical properties caused by grain growth during slow SPF processes, for example. Furthermore, as the processing time can be significantly reduced, the possibilities of α -case or oxygen enrichment of the surface is minimized and no protective atmosphere (which is used in SPF processes), such as argon, is required.

Preferably, the method further comprises maintaining the sheet material within the dies after forming until the temperature of the sheet material is less than the finish temperature for β to martensite transformation within the sheet material. In some conventional approaches the material may be maintained in hot dies for hours or even days while it cools to a stable temperature. Use of relatively cold dies allows the method to incorporate quenching within the dies (in order to avoid thermal distortion during cooling, for example) but can be substantially quicker.

Improved shape accuracy can be achieved by the method of this aspect due to: i) low flow stress at high temperature β /near- β phase region (β is softer phase compared to α) resulting in negligible residue stress; ii) diminished thermal distortion by cooling in closed-dies; and further reduced springback because of martensite phase transformation during quenching for two-phase Ti-alloys or Ni-alloys.

In preferred embodiments, the sheet material is maintained within the dies after forming until the temperature of the sheet material is less than 400°C. At this temperature the chance of thermal distortion during further cooling is low. Preferably, the temperature of the dies is less than 400°C. This can enable sufficient cooling of the material within the dies after forming as well as relatively fast cooling during forming itself. In some embodiments, the dies are at room temperature, with no requirement to heat them at all.

In preferred embodiments, the forming step is carried out in less than 10 seconds, more preferably less than 1 second. In this manner, the forming is complete before the material cools and undergoes significant changes. Preferably, during the forming step, the sheet material is cooled at a rate of more than the lowest cooling rate at which martensite transformation from β can occur, which is 18°C/s for un-deformed Ti-6Al-4V. This offers improved final material properties.

Preferably, the step of forming is carried out no more than 5 seconds after the step of heat treating is completed. This minimises the chance of the formation of unwanted material phenomena.

In preferred embodiments, the step of heat treating occurs at a first location and a step of forming occurs at a second location and wherein the method further comprising transferring the sheet material from the first location to the second location. This facilitates the provision of different ambient temperatures.

The step of forming preferably comprises closing the dies in order to stamp the sheet material to take the predefined configuration. This process of stamping is well tested and can facilitate many configurations.

In preferred embodiment, the method may comprise annealing the sheet material after the step of forming. Annealing the material can improve its properties.

Brief Description of the drawings

Preferred embodiments of the disclosure will now be described with reference to the accompanying drawings, in which:

Figure 1 shows a temperature profile of an embodiment of the disclosure in comparison with prior art approaches;

Figure 2 shows temperatures for a material which have effects on material properties; and

Figure 3 illustrates a process according to a preferred embodiment in comparison with conventional approaches.

5 Detailed Description

Figure1 illustrates the Heat Stamping (HS) process according to a preferred embodiment, The HS process is a hybrid forming process of heat treatment and fast stamping to
10 produce complex-net-shape Ti-alloy panels. In comparison with prior art approaches, the HS process may significantly reduce energy consumption and manufacturing cost. The process is to (i) heat treat a Ti-alloy sheet blank to β /near- β phase region at a heating station; (ii) position the sheet blank to a set of low-temperature dies; (iii) stamp the sheet at high speed by closing the dies within a short time (preferably less than 1s); (iv) quench
15 the deformed part in closed-dies.

Figure 1 shows a schematic of the Heat Stamping (HS) process, compared with conventional isothermal hot forming (IF) and superplastic forming (SPF) processes. β -transus is the lowest temperature at which a full beta phase exists; example temperatures
20 are defined according to Ti-6Al-4V.

As mentioned previously, during step (i) the Ti-sheet is heat treated to full/near-full soft-ductile β phase region, with reduced strain softening caused by α globularisation. As such, the final temperature at the end of the heat treating step of step (i) is close to the β -
25 transus temperature for that material, preferably within 100°C, more preferably within 10°C, of that temperature. In the preferred embodiments, the final temperature is within this range and also below the β -transus temperature.

The purpose of the heat treatment is to obtain desired microstructure for both favoured
30 formability and post-form mechanical properties. The heat treatment can be integrated with conventional heat treating processes, such as β annealing, recrystallization annealing, solution treating, etc. To minimize the β grain growth, strictly controlled heating time and temperature can be adopted. In preferred embodiments, relatively fast heating processes are adopted. Fast heating can be realised by advanced heating techniques,
35 such as resistance heating, induction heating, etc.

At step (ii) the transfer between the heating station and the location of the dies is carried out quickly. Preferably, this step is completed within 10 seconds, more preferably within 2 seconds.

- 5 At step (iii) the material is stamped using low-temperature dies. "Low-temperature" in this context is a relative term, and may mean that the dies are less than 500°C for example, or more preferably less than 350°C. In some examples the dies may be at room temperature, but this is not essential. The use of low temperature dies can improve the efficiency of the process.

10

The speed of the stamping process at step (iii) is selected to be high enough to: (a) reduce temperature loss in cold-dies stamping and ensure the forming is completed above $(\beta \rightarrow M)_{\text{start}}$ (i.e. the temperature at which $\beta \rightarrow M$ transitions start); (b) minimize diffusion-driven microstructural evolutions including β to α phase transformation, static
15 globularisation, static recovery; and (c) maximize strain hardening and strain rate hardening effects to enhance formability. Preferably, the stamping process is such that forming is completed within 10 seconds, more preferably within 1 second.

Typically, a higher cooling rate enables finer microstructural features (e.g. smaller α
20 colonies and smaller width of α lamellae) to be generated, which is positive for post-form strength and fatigue strength. When the cooling rate exceeds a critical value, martensite transformation can take place in a two-phase alloy, illustrated in Fig. 2, which enables material hardening by subsequent age annealing. Accordingly, the critical cooling rate in preferred embodiments is the lowest cooling rate at which martensite (M) transformation
25 from β can occur. This is 18°C/s for un-deformed Ti-6Al-4V, for example, which is easy to achieve for sheet Ti-alloys during die quenching (step (iv)).

Heat transfer is an important factor of this process to control the cooling rate, which relates to die surface texture, contact pressure, clearance, lubrication, die temperature,
30 and sheet thickness. For less energy consumption and die wear, lower die temperature is preferred (the optimum condition is that no heating of dies is required at all), provided the forming can be completed fast enough.

It will be recognised that the temperature profile of heat treatment step does not need to
35 follow the schematic in Figure 1. It can be flexible and designed for desired the microstructural evolutions, as long as the final temperature is close to, equal to or above the β -transus temperature.

For example, during the heat treatment step, the Ti-alloy sheet may be heated above β transus temperature, which can enable full acicular martensite to be obtained after forming and cold die quenching. In another example, if a specific as-rolled two-phase Ti-
5 alloy sheet (without recrystallization and annealing) is used as starting material for the HS process, the sheet can be heated to and soaked at a low recrystallization annealing temperature for a period of time (e.g. 800-850 °C for Ti-6Al-4V) allowing generation of more dispersed equiaxed primary α ; once this has occurred to the desired extent, the sheet may be further heated up to the higher final temperature around β transus
10 temperature at very high heating rate, disallowing equiaxed primary α phase to be fully dissolved, which can enable bi-modal microstructure to be obtained in final components for best fatigue strength than other microstructure types.

In general, it should be understood that the HS process can provide not just
15 manufacturing but heat treatment benefits. This is not the case in IF or SPF processes, in which the heating step is carried out solely to provide ductility for the forming step. In the HS process of the present disclosure, the heating and forming temperatures are decoupled, which adds more flexibility on microstructural control during the forming process for better formability and post-form properties.

20

This can be understood from Figure 3, which illustrates the HS process integrated into a manufacturing chain (lower branch of the Figure) in comparison with conventional approaches (upper branch of the Figure). In the upper branch, after homogenization and rolling to form initial sheet material, a specific heat treatment process is carried out before
25 the forming process (which can be cold forming (CF), isothermal hot forming (IF/HF) or superplastic forming (SPF)). Later heat treatments may also be incorporated. While HF/CPF processes do themselves include a heating step, there is no flexibility to account for desired material properties, instead the heating within those processes is focussed on ductility for forming and is designed to minimise material effects. In contrast, due to the
30 decoupling of forming and heating temperatures in the HS process of the present disclosure, the HS process can be optimised for heat treatment of material properties as well as physical manufacture.

The HS process may comprise an additional annealing step after forming, to alter the
35 microstructures for desired post-form mechanical properties. The microstructural evolutions during annealing would occur providing the Ti-alloy is quenched at a cooling rate higher than a critical value. For example, precipitation of secondary α phase (α

platelets) in supersaturated β (martensite) will occur for Ti-6Al-4V aging treated at 500°C to obtain increased final strength. For conventional IF/SPF processes, to enable age hardening, an additional heat treatment (solution treating and quenching) step is needed between forming and ageing. Quenching without die holding would easily cause thermal distortion for thin panel components.

Although the above description relates principally to Ti-alloys, the present disclosure may also find utility in the context of Ni-alloys.

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Claims

1. A method for forming a component from a Ti-alloy or Ni-alloy sheet material, comprising:
 - 5 heat treating the sheet material, wherein a final temperature of the sheet material is above 100°C below a β -transus temperature of the sheet material;
forming the sheet material into a predefined configuration between two dies, wherein forming is completed before the temperature of the sheet material reaches a start temperature for β to martensite transformation within the sheet material and wherein the
10 temperature of the dies is less than a finish temperature for β to martensite transformation within the sheet material.
2. A method according to claim 1, further comprising maintaining the sheet material within the dies after forming until the temperature of the sheet material is less than the
15 finish temperature for β to martensite transformation within the sheet material.
3. A method according to claim 2, wherein the sheet material is maintained within the dies after forming until the temperature of the sheet material is less than 500°C.
- 20 4. A method according to any one of the preceding claims, wherein the temperature of the dies is less than 500°C.
5. A method according to claim 4, wherein the dies are at room temperature.
- 25 6. A method according to any one of the preceding claims, wherein the forming step is carried out in less than 10 seconds, preferably less than 1 second.
7. A method according to any one of the preceding claims, wherein during the forming step, the sheet material is cooled at a rate of more than 18°C/s.
30
8. A method according to any one of the preceding claims, wherein the step of forming is carried out no more than 5 seconds after the step of heating is completed.
9. A method according to any one of the preceding claims, wherein the step of heat
35 treating occurs at a first location and a step of forming occurs at a second location and wherein the method further comprising transferring the sheet material from the first location to the second location.

10. A method according to any one of the preceding claims, wherein the step of forming comprises closing the dies in order to stamp the sheet material to take the predefined configuration.

5

11. A method according to any one of the preceding claims, further comprising annealing the sheet material after the step of forming.

1/2

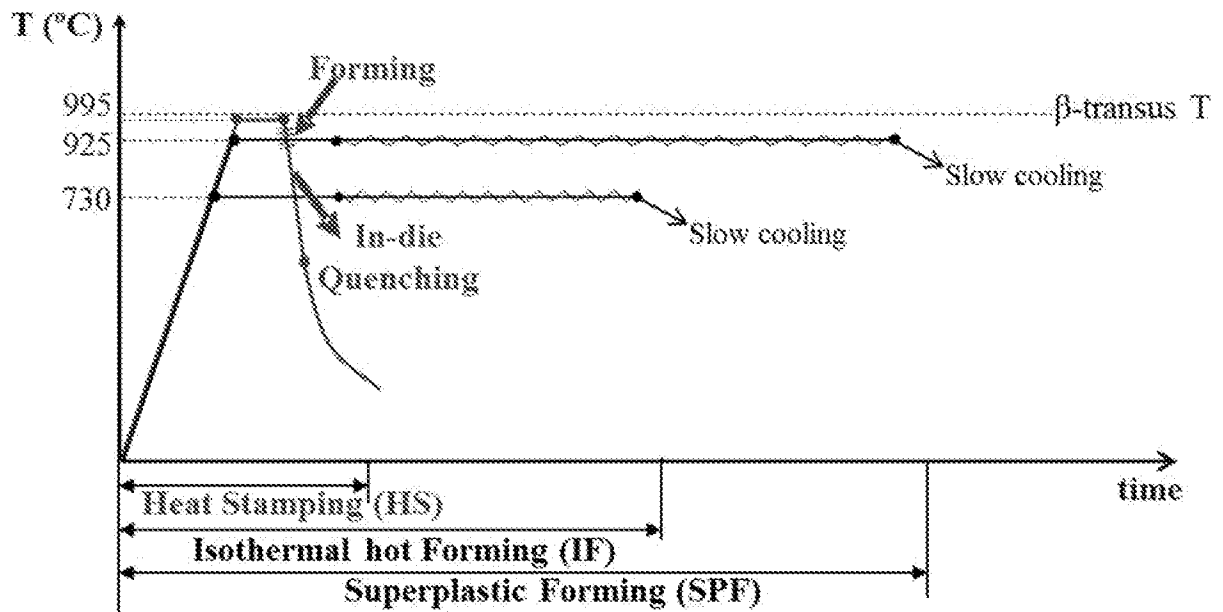


Fig 1

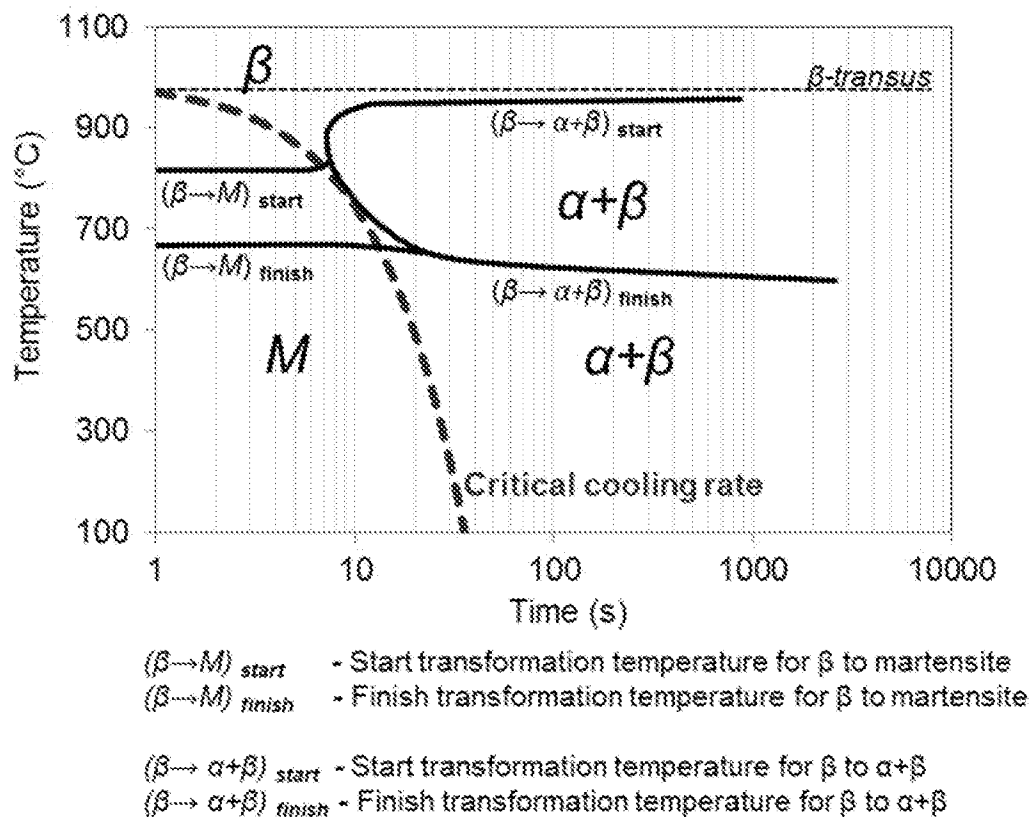


Fig 2

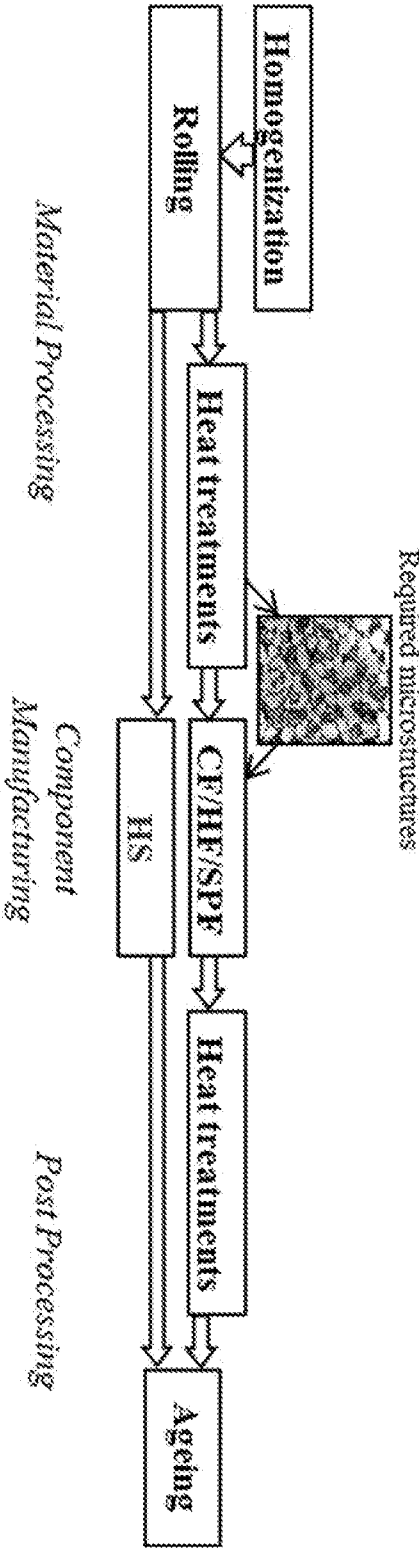


Fig 3

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2018/052374

A. CLASSIFICATION OF SUBJECT MATTER

INV. C22F1/18 C22F1/10 B21D22/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22F C22C B21D C21D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2008/059242 A2 (UNIV BIRMINGHAM [GB]; LIN JIANGUO [GB]; DEAN TREVOR A [GB]; GARRETT RI) 22 May 2008 (2008-05-22) page 3, lines 22-27; claims 1,5-9 page 7, lines 7-8, 14-16 page 8, lines 26-28 -----	1-11
A	FR 2 982 279 A1 (SNECMA [FR]) 10 May 2013 (2013-05-10) page 4, lines 21-25; claim 1; figure 3 -----	1-11
A	FR 2 620 956 A1 (INST FRANCAIS DU PETROLE [FR]) 31 March 1989 (1989-03-31) the whole document -----	1-11
A	JP S63 130755 A (SUMITOMO METAL IND) 2 June 1988 (1988-06-02) abstract; figures 1-3 -----	1-11



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2018/052374

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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