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Erittäin korkean mekaanisen lujuuden omaava kuumamuokattu juotettu teräskappale sekä valmistusmenetelmä

Svetsat varmformat stålelement med mycket hög mekanisk hållfasthet samt framställningsförfarande

HOT-FORMED WELDED PART HAVING HIGH RESISTANCE AND PROCESS TO PRODUCE SUCH A PART

(56) Viitejulkaisut - Anförda publikationer - References cited
EP-A1- 1 878 531; WO-A1-2007/118939; US-B1- 6 290 905;

Hot-formed welded steel part of very high mechanical strength, and method of fabrication

The invention relates principally to a hot-formed welded steel part of very high mechanical strength.

The invention also relates to a method of fabricating such a welded steel part, as well as to the use of this welded steel part for fabricating structural parts or safety parts for a motor vehicle.

It is known to fabricate welded steel parts from steel blanks of different composition and/or thickness which are butt-welded to one another in a continuous fashion. According to a first known mode of fabrication, these welded blanks are cold-formed. According to a second known mode of fabrication, these welded blanks are heated to a temperature that allows the austenitization of the steel and then are hot-formed and rapidly cooled within the forming die. The present invention relates to this second mode of fabrication.

The composition of the steel can be selected both to allow subsequent heating and forming operations and to confer on the welded steel part a high mechanical strength, high impact resistance and good corrosion resistance.

Such steel parts are used in particular in the automobile industry, and more particularly for fabricating anti-intrusion parts, structural parts or parts involved in the safety of motor vehicles.

Among the hot-formable materials having the necessary characteristics for the applications mentioned above, the coated steel sheet which forms the subject matter of the publication EP971044 contains in particular a carbon content of between 0.10% and 0.5% by weight and comprises an aluminium-based metal pre-coating. The sheet is coated, for example by continuous dip-coating, in a bath comprising, besides aluminium, silicon and iron in controlled amounts. The subsequent heat treatment applied during a hot-forming process or after the forming and the cooling carried out after this heat treatment makes it possible to obtain a martensitic microstructure which confers on the steel part a high mechanical strength that may exceed 1500 MPa.

One known method of fabricating welded steel parts consists in providing at least two steel sheets according to the publication EP971044, in butt-welding these two sheets so as to obtain a welded blank, optionally in cutting this welded blank, then in heating the welded blank before carrying out hot forming, for example by hot stamping, to confer on the steel part the shape required for use.

One known welding technique is laser beam welding. This technique has advantages in terms of flexibility, quality and productivity in comparison to other welding techniques such as seam welding or arc welding.

However, during the welding operation, the aluminium-based pre-coating consisting of an intermetallic alloy layer in contact with the steel substrate, overlaid with a metal alloy layer, is diluted with the steel substrate within the molten zone, which is the zone that is brought to the liquid state during the welding operation and that solidifies after this welding operation, thereby forming the bond between the two sheets.

In the range of aluminium contents of the pre-coating, two situations may then occur.

According to a first phenomenon, if the aluminium concentration in the molten zone is locally high, intermetallic compounds form, resulting from the dilution of a portion of the pre-coating within the molten zone and from the alloying which occurs during the subsequent heating of the welded join prior to the hot forming step. These intermetallic compounds are sites where fractures are likely to start.

According to a second phenomenon, if the aluminium concentration in the molten zone is not as high, the aluminium, which is an alpha phase stabilizer in solid solution in the matrix, prevents the transformation into austenite which occurs during the heating step preceding the stamping. As a result, it is no longer possible to obtain martensite or bainite during the cooling after the hot forming, and the welded join contains ferrite. The molten zone then has a lesser hardness and mechanical strength than the two adjacent sheets.

For avoiding the first phenomenon described above, one solution is described in the publication EP2007545, which consists in removing the superficial metal alloy layer at the periphery of the sheets intended to undergo the welding operation, leaving the intermetallic alloy layer. The removal may be carried out by brushing or by laser beam.

The intermetallic alloy layer is maintained in order to ensure the corrosion resistance and to avoid the phenomena of decarburization and oxidation during the heat treatment preceding the forming operation.

However, this technique does not always make it possible to avoid the second phenomenon described above: although the dilution of the thin intermetallic alloy layer leads only to a very slight increase in the aluminium content in the molten zone (less than 0.1%), the conjugation of the local aluminium segregations and of the possible combination of boron in the form of nitride in the molten zone leads to a decrease in the hardenability of this zone. As a result, the critical quenching rate is increased in the molten zone in comparison to that of the two adjacent sheets.

Fig. 1 shows the hardness observed in the molten zone (profile 2) and in the base metal (profile 1), that is to say the neighbouring steel sheet, after heating to 900°C then hot stamping and cooling at a variable rate. The hardness of the base metal is the hardness obtained in the case of a sheet according to the publication EP971044, which comprises in particular 0.22% C, 1.12% Mn and 0.003% B. The hardness of the molten zone is the hardness observed when the welding is carried out as described in the publication EP2007545.

Profile 1 indicates that the critical martensitic quenching rate of the base metal is 27°C/second since any cooling rate greater than 27°C/second leads to a hardness of the sheet of around 480 HV and to a completely martensitic microstructure.

On the other hand, profile 2 shows that the critical martensitic quenching rate of the molten zone is 35°C/s. Thus, a cooling rate after hot stamping of between 27°C/s and 35°C/s will not confer a sufficient hardness and a completely martensitic structure in this zone.

Moreover, this increase in the critical quenching rate in the molten zone is accompanied by unfavourable cooling conditions in this molten zone during the hot forming.

This is because the molten zone may be in total lack of contact with the cold die during the cooling for the following independent or combined reasons:

- if the two sheets have a different thickness, on account of the “step” created in the die to enable the displacement of the material during the forming
- on account of a possible misalignment between the die and the welded blank.

As a result of what has been stated above, for a cooling rate of the welded blank of less than 35°C/s, the molten zone has a microstructural heterogeneity and a decrease in the mechanical characteristics of the join, which may render the welded steel part unsuitable for the required applications, in particular for the automobile industry.

Another known welding method applied to the sheets of the publication EP971044 is described in the publication EP1878531.

This method consists in creating a molten zone which has the required mechanical strength characteristics by welding two sheets which have previously been cut by shearing and which have, on account of this type of cutting, deposits of the aluminium-based pre-coating on their cut faces.

The welding method consists either of a hybrid laser-TIG welding, that is to say a laser beam combined with an electric arc generated by a TIG ("Tungsten Inert Gas") welding torch equipped with a non-fusible electrode, or of a hybrid laser-MIG ("Metal Inert Gas") welding for which the welding torch is equipped with a fusible wire electrode.

However, the welded steel parts hot-stamped after the operation of welding according to this method also exhibit mechanical fragility at the molten zone.

This is because, regardless of the proportion of filler metal in the case of hybrid laser-MIG welding, the mixing within the molten zone is not sufficient to avoid the formation of zones with a high aluminium content, which lead to a lack of martensite formation in the molten zone during the cooling and thus to insufficient mechanical strength.

In order to obtain a desired level of dilution, it is necessary to add large amounts of filler metal, which on one hand cause difficulties when melting the metal added by the welding with the metal to be welded, and on the other hand cause a considerable excess thickness in the molten zone which is bothersome for the forming operation and which means that the resulting part to be welded does not meet the quality standards in force in the automobile sector.

In this context, the present invention relates to a welded steel part of very high mechanical strength, that is to say greater than 1230 MPa, obtained by a heating in the austenitic range followed by the forming of at least one welded blank obtained by butt-welding of at least two sheets consisting at least partly of a steel substrate and of a pre-coating which consists of an intermetallic alloy layer in contact with the steel substrate, overlaid with a metal alloy layer which is an aluminium or aluminium-based alloy.

The invention relates in particular to such a welded steel part for which the prior forming consists of a hot forming and for which the mechanical strength of the molten zone is greater than that of the two welded sheets or of at least one of the two welded sheets.

To this end, the welded steel part of very high mechanical strength according to the invention is obtained by a heating in the austenitic range followed by a hot forming then by a cooling of at least one welded blank obtained by butt-welding of at least a first and a second sheet consisting at least partly of a steel substrate and of a pre-coating which consists of an intermetallic alloy layer in contact with the steel substrate, overlaid with a metal alloy layer composed of an aluminium or aluminium-based alloy, and is essentially characterised in that the edges in direct proximity to the molten zone resulting from the welding operation and forming the bond between the first and the second sheets are devoid of the metal alloy layer while being provided with the intermetallic alloy layer, and in that, over at least part of the length of the molten zone, the ratio between the carbon content of the molten zone and the carbon content of the substrate of that of one of the first or second sheet that has the highest carbon content Cmax is between 1.27 and 1.59.

The composition of the substrate of at least the first or the second sheet comprises, the contents being expressed by weight:

$0.10\% \leq C \leq 0.5\%$

$0.5\% \leq Mn \leq 3\%$

$0.1\% \leq Si \leq 1\%$

$0.01\% \leq Cr \leq 1\%$

$Ti \leq 0.2\%$

$Al \leq 0.1\%$

$S \leq 0.05\%$

$P \leq 0.1\%$

$0.0002\% \leq B \leq 0.010\%$

the balance being iron and impurities inherent in production.

Due to the aforementioned characteristics of the welded steel part of the invention, any fracture occurs in the base metal and not in the molten zone when the welded join is subjected to a uniaxial tensile stress perpendicular to the join.

The welded steel part of the invention may also include the following optional features, considered in isolation or in all possible technical combinations:

- the ratio between the hardness of the molten zone and the hardness of the substrate of that of one of the first or second sheet that has the highest carbon content Cmax is greater than 1.029 + (0.36 Cmax), Cmax being expressed as a percentage by weight.

- the composition of the substrate of at least the first or the second sheet comprises, the contents being expressed by weight:

$0.15\% \leq C \leq 0.4\%$

$0.8\% \leq Mn \leq 2.3\%$

$0.1\% \leq Si \leq 0.35\%$

$0.01\% \leq Cr \leq 1\%$

$Ti \leq 0.1\%$

$Al \leq 0.1\%$

$S \leq 0.03\%$

$P \leq 0.05\%$

$0.0005\% \leq B \leq 0.010\%$

the balance being iron and impurities inherent in production.

- the composition of the substrate of at least the first or the second sheet comprises, the contents being expressed by weight:

$0.15\% \leq C \leq 0.25\%$

$0.8\% \leq Mn \leq 1.8\%$

$0.1\% \leq Si \leq 0.35\%$

$0.01\% \leq Cr \leq 0.5\%$

$Ti \leq 0.1\%$

$Al \leq 0.1\%$

$S \leq 0.05\%$

$P \leq 0.1\%$

$0.0002\% \leq B \leq 0.005\%$

the balance being iron and impurities inherent in production.

- the carbon content of the molten zone is less than or equal to 0.35% by weight.

- the metal alloy layer of the pre-coating comprises, the contents being expressed by weight, between 8 and 11%

silicon, between 2 and 4% iron, the remainder of the composition being aluminium and inevitable impurities.

- the microstructure of the molten zone is devoid of ferrite.
- the microstructure of the molten zone is martensitic.
- said hot forming of the welded blank is carried out by a hot stamping operation.
- the respective cut faces of the peripheral edges of the first and second sheets intended to undergo the welding operation are devoid of aluminium or of aluminium alloy, the presence of which may result from an earlier operation of cutting each of the first and second sheets.

The invention also relates to a method of fabricating the welded steel part as described above.

To this end, according to the method of the invention, at least a first and a second steel sheet are provided, consisting of a steel substrate and a pre-coating which consists of an intermetallic alloy layer in contact with the steel substrate, overlaid with a metal alloy layer which is composed of aluminium alloy or aluminium-based alloy, and for which at least one face of a portion of a peripheral edge of each of the first and second steel sheets intended to undergo the welding operation is devoid of said metal alloy layer while leaving in place the intermetallic alloy layer, and for which the respective cut faces of the peripheral edges of the first and second sheets intended to undergo the welding operation are devoid of aluminium or of aluminium alloy, the presence of which may result from an earlier operation of cutting each of the first and second sheets, then the first and the second steel sheets, at the respective peripheral edges of these first and second steel sheets that are devoid of the metal alloy layer, are butt-welded using a protective gas by means of a laser source and by using a material filler wire over at least part of the length of the welded zone, a welded blank is obtained, in which the carbon content of the molten zone resulting from the welding operation and forming the bond between the first and second sheets is between 1.27 and 1.59 times the carbon content of the substrate of the sheet that has the highest carbon content, then said welded blank is heated so as to confer a completely austenitic structure in the molten zone, then said welded and heated blank is hot-formed so as to obtain a steel part, then said steel part is cooled at a controlled rate so as to obtain the intended mechanical strength characteristics.

The composition of the substrate of at least the first or the second sheet comprises, the contents being expressed by weight:

$0.10\% \leq C \leq 0.5\%$

$0.5\% \leq Mn \leq 3\%$

$0.1\% \leq Si \leq 1\%$

$0.01\% \leq Cr \leq 1\%$

$Ti \leq 0.2\%$

$Al \leq 0.1\%$

$S \leq 0.05\%$

$P \leq 0.1\%$

$0.0002\% \leq B \leq 0.010\%$

the balance being iron and impurities inherent in production.

The filler wire comprises, the contents being expressed by weight:

$0.6\% \leq C \leq 1.5\%$

$1\% \leq Mn \leq 4\%$

$0.1\% \leq Si \leq 0.6\%$

$Cr \leq 2\%$

$Ti \leq 0.2\%$

the balance being iron and impurities inherent in production.

The method of fabricating the welded steel part of the invention may also include the following optional features, considered in isolation or in all possible technical combinations:

- the opposite faces of the respective peripheral edges of each of the first and second steel sheets are devoid of metal alloy layer, while leaving in place the intermetallic alloy layer.
- the width of the zone devoid of metal alloy layer at the peripheral edge of the first and second sheets intended to undergo the welding operation is between 0.2 and 2.2 millimetres.
- the composition of the substrate of at least the first or the second sheet comprises, the contents being expressed by weight:

$0.15\% \leq C \leq 0.4\%$

$0.8\% \leq Mn \leq 2.3\%$

$0.1\% \leq Si \leq 0.35\%$

$0.01\% \leq Cr \leq 1\%$

$Ti \leq 0.1\%$

$Al \leq 0.1\%$

$S \leq 0.03\%$

$P \leq 0.05\%$

$0.0005\% \leq B \leq 0.010\%$

the balance being iron and impurities inherent in production.

- the composition of the substrate of at least the first or the second sheet comprises, the contents being expressed by weight:

$0.15\% \leq C \leq 0.25\%$

$0.8\% \leq Mn \leq 1.8\%$

$0.1\% \leq Si \leq 0.35\%$

$0.01\% \leq Cr \leq 0.5\%$

$Ti \leq 0.1\%$

$Al \leq 0.1\%$

$S \leq 0.05\%$

$P \leq 0.1\%$

$0.0002\% \leq B \leq 0.005\%$

the balance being iron and impurities inherent in production.

- during the welding step, the peripheral edges to be welded of the first and second steel sheets are arranged at a maximum distance of 0.1 millimetre from one another.
- the linear welding energy of said laser source during the welding operation is greater than 0.3 kJ/cm.
- the laser source is either of the CO_2 gas laser type, which confers a linear welding energy greater than 1.4 kJ/cm, or of the solid-state laser type, which confers a linear welding energy greater than 0.3 kJ/cm.
- the welding speed is between 3 metres/minute and 8 metres/minute, and the power of the CO_2 gas laser is greater than or equal to 7 kW and the power of the solid-state laser is greater than or equal to 4 kW.

The welding step is carried out under a helium and/or argon protective gas.

- the flow rate of helium and/or of argon during the welding step is greater than or equal to 15 litres per minute.

- the filler wire comprises, the contents being expressed by weight:

  $0.65\% \leq C \leq 0.75\%$

  $1.95\% \leq Mn \leq 2.05\%$

  $0.35\% \leq Si \leq 0.45\%$

  $0.95\% \leq Cr \leq 1.05\%$

  $0.15\% \leq Ti \leq 0.25\%$

the balance being iron and impurities inherent in production.

- the proportion of filler metal relative to the volume of the molten zone is between 12% and 26%, and the welding speed is between 3 and 7 metres per minute.

- the pair consisting of said proportion of filler metal relative to the volume of the molten zone and the welding speed are within the range illustrated in Fig. 8.

- the pair consisting of said proportion of filler metal relative to the volume of the molten zone and the welding speed meets the following combined requirements:
  - the proportion of filler metal relative to the volume of the molten zone is between 12% and 26%, and
  - the welding speed is between 3 and 7 metres per minute, and
  - when the welding speed is greater than 3.5 metres per minute, the pair consisting of the proportion of filler metal relative to the volume of the molten zone (35) and the welding speed is such that $Y \leq -3.86X + 39.5$, it being understood that Y denotes the proportion of filler metal expressed as a percentage by volume and that X denotes the welding speed expressed in metres per minute.

- the proportion of filler metal relative to the volume of the molten zone (35) is between 14 and 16%, the flow rate of helium and/or of argon is between 13 and 17 litres per minute, the diameter of the laser beam (30) at the point of impact on the sheet is between 500 and 700 micrometres, and the end (32a) of the filler wire (32) is located at a distance of between 2 and 3 millimetres from the point of impact of the laser beam on the sheet.
- the cooling rate of the molten zone (35) during the hot forming step is greater than or equal to the critical martensitic quenching rate of said molten zone (35).

Finally, the invention relates to the use of the steel part described above for fabricating structural parts or safety parts for a vehicle, in particular for a motor car.

Other features and advantages of the invention will emerge clearly from the description thereof which is given below, purely by way of example and in a non-limiting manner, with reference to the appended figures, in which:

- Fig. 1, which has already been mentioned, shows the comparative profile of the hardness of the base metal and of the molten zone as a function of the cooling rate during the hot stamping, for a welded steel part of the prior art,
- Fig. 2 is a schematic diagram of a sheet used for implementing the method of the invention,
- Fig. 3 is a schematic diagram of the start of the welding operation of the method of the invention,
- Fig. 4 is a schematic diagram of the end of the welding operation of the method of the invention,
- Fig. 5 shows the profile of the mechanical tensile strength of the molten zone, the stress being exerted perpendicularly in relation to the welded join, as a

function of the percentage of filler metal in the molten zone during the method of the invention, and for two different cooling rates during the hot stamping,

- Fig. 6 shows the location of the fracture, either in the base metal or in the molten zone, as a function of the ratio between the carbon content of the molten zone and the carbon content of the base metal,
- Fig. 7 is a graph showing an example of a micro-hardness profile (hardness under a load of 200 g) of a welded steel part fabricated from two sheets of different thickness and stamped according to the invention and of the zone adjacent to said molten zone, and
- Fig. 8 is a graph showing the limit conditions for optimum functioning of the method of the invention in terms of percentage of filler metal and welding speed,
- Fig. 9 shows the variation of toughness in the molten zone as a function of the temperature, for different carbon contents.

According to the method of the invention, two sheets coated by immersion in a bath of molten aluminium according to a method known as continuous "dip coating" according to the publication EP971044 are provided. The term sheet is intended in a broad sense to mean any strip or object obtained by cutting from a strip, coil or sheet.

The aluminium bath used in the dipping operation may additionally comprise from 9 to 10% silicon and from 2 to 3.5% iron.

The steel constituting the steel substrate of the sheets has the following composition, the contents being expressed by weight:

$0.10\% \leq C \leq 0.5\%$
$0.5\% \leq Mn \leq 3\%$
$0.1\% \leq Si \leq 1\%$
$0.01\% \leq Cr \leq 1\%$
$Ti \leq 0.2\%$
$Al \leq 0.1\%$
$S \leq 0.05\%$
$P \leq 0.1\%$
$0.0002\% \leq B \leq 0.010\%$

the balance being iron and impurities inherent in production.

Preferably, the composition of the steel will be as follows:

$0.15\% \leq C \leq 0.4\%$
$0.8\% \leq Mn \leq 2.3\%$
$0.1\% \leq Si \leq 0.35\%$
$0.01\% \leq Cr \leq 1\%$
$Ti \leq 0.1\%$
$Al \leq 0.1\%$
$S \leq 0.03\%$
$P \leq 0.05\%$
$0.0005\% \leq B \leq 0.010\%$

the balance being iron and impurities inherent in production.

More preferably, and according to the description below, the composition of the steel will be as follows:

$0.15\% \leq C \leq 0.25\%$
$0.8\% \leq Mn \leq 1.8\%$
$0.1\% \leq Si \leq 0.35\%$
$0.01\% \leq Cr \leq 0.5\%$
$Ti \leq 0.1\%$

Al ≤ 0.1%
S ≤ 0.05%
P ≤ 0.1%
0.0002% ≤ B ≤ 0.005%

the balance being iron and impurities inherent in production.

The composition of the sheets intended to be welded to one another may be identical or different.

The coating, which will be called the "pre-coating" at this stage in the description that follows, has the following characteristics resulting from the immersion of the sheet in the aluminium bath: with reference to Fig. 2, the pre-coating 3 of the sheet 4 has two layers 5, 7 of different nature.

First, an intermetallic alloy layer 5 of the AlSiFe type is in contact with the surface of the steel substrate 6 of the sheet 4. This intermetallic alloy layer 5 results from the reaction between the steel substrate 6 and the aluminium bath.

In addition, this intermetallic alloy layer 5 is overlaid with a metal alloy layer 7 which forms a surface layer of the pre-coating 3.

The pre-coating 3 is present on the two opposite faces 8a, 8b of the sheet 4.

According to the method of the invention, the metal alloy layer 7 is removed at the periphery 9 of the sheet 4 which is intended to undergo the subsequent welding operation.

In Fig. 2, this removal has taken place only on the upper face 8a, but advantageously the metal alloy layer 7 will be removed peripherally at the two opposite faces 8a, 8b of the sheet 4.

The intermetallic alloy layer 5 therefore remains at the periphery 9 of the sheet 4 intended to undergo the welding operation.

The ablation of the metal layer 7 may be carried out by a brushing operation since the metal layer 7 which is removed has a hardness that is less than the hardness of the intermetallic alloy layer 5 which remains.

A person skilled in the art will know how to adapt the parameters relating to the brushing in order to make it possible to remove the metal layer 7 at the periphery 9 of the sheet 4.

It is also possible to remove the metal alloy layer by means of a laser beam directed towards the periphery 9 of the sheet 4.

The interaction between the laser beam and the pre-coating 3 causes a vaporization and an expulsion of the metal alloy layer 7.

The width over which the metal alloy layer 7 is removed at the periphery 9 of the sheet 4 is between 0.2 and 2.2 millimetres.

Furthermore, the thickness of the intermetallic alloy layer 5 remaining at the periphery 9 of the sheet 4 has a thickness of around 5 micrometres.

These two modes of ablation (brushing and laser) of the metal alloy layer form the subject matter of the publication EP2007545.

The earlier operations of cutting the sheet 4, as well as the operation of removing the metal alloy layer 7 as described above, may lead to the entrainment of a portion of the pre-coating 3 onto the cut face 10 of the periphery 9 of the sheet 4 intended to undergo the welding operation. This then results in traces of aluminium or of aluminium alloy on this cut face 10.

According to the method of the invention, these traces of aluminium or of aluminium alloy on the cut face 10 of the sheet 4 are also removed by brushing prior to the welding operation.

With reference to Fig. 3, a first sheet 11 and a second sheet 12, each having a respective substrate 25, 26 and each having on their respective opposite faces 13a, 13b; 14a; 14b a pre-coating 15, 16 consisting of an intermetallic alloy layer 17, 18 overlaid with a metal alloy layer 19, 20, are placed end to end according to conventional laser welding practice by contact between their respective peripheries 21, 22, on which on the one hand the metal alloy layer 19, 20 has been removed at their opposite faces 13a, 13b; 14a; 14b, and on the cut faces 23, 24 from which the pre-coating 15, 16 entrained during the shearing operation has also been removed.

The maximum distance between the respective cut faces 23, 24 of the two sheets 11, 12 is 0.1 millimetre, the forming of this gap between the cut faces 23, 24 of the two sheets 11, 12 encouraging the deposit of the filler metal during the welding operation.

As illustrated in Fig. 3, the welding operation according to the method of the invention consists of a laser beam 30 directed at the join between the two sheets 11, 12, combined with a filler wire 32 that melts at the point of impact 31 of the laser beam. It is therefore a laser welding method using filler metal.

The laser source used must be high-powered and can be selected from a laser source of the CO_2 gas laser type with a wavelength of 10 micrometres or a solid-state laser source with a wavelength of 1 micrometre.

On account of the thickness of the two sheets 11, 12, which is less than 3 millimetres, the power of the CO_2 gas laser will be greater than or equal to 7 kilowatts while the power of the solid-state laser will be greater than or equal to 4 kilowatts.

Furthermore, the diameter of the laser beam at the point of impact thereof on the sheets will be around 600 micrometres for the two types of laser source.

Finally, the end 32a of the filler wire 32 will be located at a distance of around 3 millimetres from the point of impact P of the laser beam 30 on the join between the sheets 11 and 12 for a solid-state laser source and at a distance of around 2 millimetres from the laser beam 30 for a laser source of the CO_2 gas laser type.

These conditions will make it possible to obtain a complete melting of the filler wire 32 as well as a satisfactory mixing with the steel substrate at the weld.

In addition, these powers will make it possible to use a welding speed sufficient to avoid the precipitation of boron nitrides and/or other segregation problems.

The filler wire must meet two requirements:

- first, the quantity of metal added by this filler wire 32 must make it possible for the laser source to bring about the complete melting thereof and to produce a relatively homogeneous mixture at the weld. In addition, the quantity of metal added must not lead to an excess thickness of the weld of more than 10% relative to the smallest thickness of the two sheets if the latter are not of the same thickness, in accordance with the automobile quality standards in force.
- furthermore, the composition of the filler wire must make it possible, in combination with the other parameters of the welding process, to obtain a weld having mechanical strength characteristics which are comparable, after hot forming and cooling, to the mechanical strength characteristics of the first 11 and second 12 welded sheets.

Finally, during the welding step, a protective gas environment must be used in order to avoid the oxidation and decarburization of the zone being welded, to avoid the formation of boron nitride in the molten zone and potential cold cracking phenomena caused by the absorption of hydrogen.

This protective gas environment is achieved by using helium and/or argon.

With reference to Fig. 4, the welding operation leads to the formation of a molten zone 35 at the join between the two sheets 11, 12, which subsequently solidifies to form the weld. The term "molten zone" is still used to identify this weld even after solidification of this molten zone 35.

For the parts that will undergo a less rapid local cooling during the hot stamping, it is possible to add a filler wire only in certain parts of the length of the molten zone and not to add the filler wire in the rest of the joins.

The welded blank 37 resulting from the welding operation therefore has a molten zone 35 devoid of intermetallic alloy because of the previous removal of the metal alloy layer 19, 20 as explained above.

Furthermore, as shown in Fig. 4, the edges 36 in direct proximity to the molten zone 35 are devoid of metal alloy layer 19, 20 on account of the fact that the width of the molten zone 35 is less than the width of the welding zone which does not include a metal alloy layer 19, 20.

Although Fig. 4 shows the simple case of a welded blank made from a first 11 and a second 12 sheet, it is possible to implement the invention on the basis of a greater number of sheets welded together.

The welded blank 37 thus obtained is then subjected to heating so as to obtain an austenitic transformation in all of the parts of this blank. The blank is hot formed, preferably by hot stamping. This step is followed by a cooling carried out by contact in the stamping die at a cooling rate which will be discussed below, and leads to a welded steel part being obtained.

In the description that follows, the reference to a welded steel part refers to the finished part after hot stamping of the welded blank, the fabrication of which is described above.

For a steel of type 22MnB5 (C=0.20-0.25%, Mn=1.1-1.35%, Si=0.15-0.35%, Al=0.020-0.060%, Ti=0.020-0.050%, Cr=0.15-0.30%, B=0.002-0.004%, the contents being expressed by weight and the balance being iron and impurities resulting from production), Table 1 below shows the welding method conditions used to fabricate a welded steel part for which the hardness of the molten and hot-stamped zone is at least equal to the hardness of one or the other of the two sheets 11, 12.

These conditions are given in terms of welding speed, volume proportion of filler metal relative to the molten zone, and chemical composition of the filler wire expressed as a percentage by weight. The tests that led to these limit conditions were carried out using a CO_2 gas laser source with a power greater than 7 kilowatts and a solid-state laser source with a power greater than 4 kilowatts under a helium and/or argon protective gas at a flow rate greater than 15 litres/minute.

	Welding speed (m/min)	Proportion of filler metal (%)	Composition of the filler wire – % by weight				
			C	Mn	Si	Cr	Ti
Minimum	3	10	0.6	1	0.1	0	0
Maximum	8	26	1.5	4	0.6	2	0.2

Table 1

In the context of another example, tests are performed with a filler wire having a composition comprising the following contents by weight: C=0.7%, Si=0.4%, Mn=2%, Cr=1% and Ti=0.2, the remainder being iron and impurities resulting from production.

The tests are performed with a CO_2 gas laser source having a power greater than 7 kilowatts and a solid-state laser source having a power greater than 4 kilowatts under a helium and/or argon protective gas at a flow rate greater than 15 litres/minute. All the results obtained, which are shown below, are similar regardless of the laser source used.

With reference to Fig. 8, the appearance of the molten zone and the quality of the mixing of the filler wire and of the molten metal are examined for different percentages of filler metal and welding speeds.

For the experimental points referenced 40 and 41, the results in terms of dilution and surface appearance of the molten zone are satisfactory, whereas for the experimental points referenced 42 the results are unsatisfactory.

Fig. 5 shows the tensile strength of the hot-stamped welded steel part as a function of the percentage of filler metal in the molten zone, for two cooling rates of 30 and 50°C/s.

The experimental points referenced 43 correspond to a cooling rate of 30°C per second and the experimental points referenced 44 correspond to a cooling rate of 50°C per second. These two rates correspond respectively to an efficient extraction of heat due to tight contact between the part and the press die (50°C/s) and to a less tight contact on account of a lower clamping pressure and/or a difference in thickness between the sheets to be welded (30°C/s).

When the hot-stamped welded blanks are cooled at a rate of 50°C per second, the mechanical tensile strength is between 1470 and 1545 MPa and the fracture occurs in the base metal.

When the hot-stamped welded blanks are cooled at a rate of 30°C per second, and when the volume proportion of filler metal is between 4.3 and 11.5%, the fracture occurs in the molten zone and the mechanical tensile strength is between 1230 and 1270 MPa.

On the other hand, when the hot-stamped welded blanks are cooled at a rate of 30°C per second, and when the volume proportion of filler metal is 14.7%, the fracture occurs in the base metal with a mechanical strength of 1410 MPa.

Therefore, a proportion of filler metal greater than 12% makes it possible to systematically obtain a fracture outside of the welded join, both in the efficiently cooled zones in the stamped part and in the less efficiently cooled zones.

Fig. 6 shows the location of the fracture, either in the base metal according to tier 45, or in the molten zone according to tier 46, when the welded joins are subjected to a uniaxial tensile force perpendicular to the join, as a function of the ratio between the carbon content of the molten zone and the carbon content of the base metal, starting from the experimental points 43, 44 discussed with reference to Fig. 5 and respectively referenced 43a and 44a in Fig. 6.

It has been shown that, when this ratio is greater than 1.27 (line D1), the fracture occurs systematically in the base metal, in spite of hardenability modifications due to the presence of aluminium in the molten zone, and in spite of the slower cooling rate resulting from imperfect contact between the part and the die. It is also shown in Fig. 6 that a particular brittleness occurs beyond a ratio of 1.59 (line D2).

This maximum ratio of 1.59 between the carbon content of the molten zone and the carbon content of the base metal is also obtained by determining the critical conditions that lead to the sudden fracture of a weld of martensitic structure comprising a surface defect, when subjected to stress perpendicular to the welding direction.

To this end, consideration is given to the case of two sheets 11, 12, the thickness w of which is 3 millimetres, and of a slot-type defect in the molten zone, the depth of which defect is 10% of the thickness of the sheets 11, 22, that is to say a depth of 0.3 millimetres.

The expression of the stress intensity factor K_I expressed in MPa$\sqrt{m}$ is as follows:

$$K_I = k\sigma\sqrt{\pi a}$$

in which

- k is the shape factor, determined in particular on the basis of the ratio a/w
- σ is the stress applied to the weld, expressed in MPa, and
- a is the depth of the defect in question, expressed in metres.

In order to evaluate the stress intensity factor, consideration is given to a case of severe stress, in which the applied stress σ is equal to the yield strength Re.

Table 2 below expresses the yield strength Re and the stress intensity factor K_I for carbon contents in the molten zone ranging between 0.2% and 0.4%, for a martensitic microstructure.

	0.2% C	0.3% C	0.35% C	0.4% C
Re (MPa)	1200	1350	1425	1500
K_I (MPa$\sqrt{m}$)	41.3	46.4	49.0	51.6

Table 2

Reference is made to Fig. 9, which shows the variation in the critical stress intensity factor K_{IC} as a function of the temperature, for carbon contents ranging between 0.2 and 0.4% and martensitic microstructures. The curve 60 relates to a carbon content of 0.2% C, the curve 61 relates to a carbon content of 0.3% C, the curve 62 relates to a carbon content of 0.35% C and the curve 63 relates to a carbon content of 0.4% C.

This Fig. 9 shows the values of the stress intensity factor K_I expressed in Table 2 for each of the carbon contents respectively referenced 64 for a carbon content of 0.2% C, 65 for a carbon content of 0.3%, 66 for a carbon content of 0.35% and 67 for a carbon content of 0.4%.

The risk of sudden fracture of the weld at -50°C is therefore avoided when the tenacity K_{IC} at this temperature is greater than the stress intensity factor K_I.

It can be seen in Fig. 9 that this condition is met provided that the carbon content does not exceed 0.35%.

The result is a maximum carbon content in the molten zone of 0.35%. Considering a welded join made from two sheets of steel of type 22MnB5, that is to say containing 0.22% carbon, the limit value of the ratio between the carbon content of the molten zone and the carbon content of the steel sheet, beyond which there is a risk of sudden fracture in the molten zone, is therefore equal to 1.59.

Furthermore, the fact that the fracture always occurs in the base metal beyond this value of 1.27 is unexpected, since the tenacity of the molten metal decreases as the carbon content increases. Coupled with the effect of stress concentration which is unavoidable in the welded join, the fracture should rather have occurred in the molten metal due to a lack of tenacity for the highest carbon levels.

To this end, the risk of sudden fracture in a weld at -50°C, as determined under the above conditions, was compared with the risk of sudden fracture at this same temperature in the base metal, the latter having a defect in the thickness of its metal coating.

Consideration is given to a micro-defect having a depth of 30 micrometres corresponding to the thickness of the metal alloy coating. For a steel of type 22MnB5 with a carbon content of 0.22%, the yield strength Re is 1250 MPa. If this steel is stressed at a stress level equal to its yield strength, the stress intensity factor K_I is 13.6 MPa.$\sqrt{m}$.

By plotting this latter value in Fig. 9 under reference 68, it is found that, in theory, the sudden fracture should occur in the molten zone and not in the base metal. However, contrary to what was expected, the inventors have found that, when the ratio between the carbon content of the molten zone and the carbon content of the base metal is between 1.27 and 1.59, the fracture systematically occurs in the base metal and not in the molten zone. In summary, the inventors have found that increasing the carbon content into this specific range makes it possible to increase the strength characteristics of the molten zone of the hot-stamped part, and does so without any worsening of the risk of sudden fracture in this zone, an unexpected effect.

Moreover, the inventors sought to define a simple method for defining the zone of the invention based on the hardness characteristics of the molten zone and of the neighbouring base metal on the hot-stamped part. The significant hardness of the molten zone is linked to its martensitic microstructure, which is exempt of ferrite. It is known that the hardness of a steel having a martensitic structure depends principally on its carbon content. Consequently, it is possible to define, on the basis of the results above, the ratio Z between the hardness of the molten zone and the hardness of the neighbouring base metal which must be respected.

When welding sheets of different composition, Cmax denotes the carbon content of that one of the sheets that has the highest carbon content. When welding identical sheets, Cmax denotes their carbon content. A fracture in the base metal during the application of tensile stress to a welded join occurs when the ratio Z is greater than a critical value dependent on Cmax, i.e. 1.029+(0.36 Cmax).

For the welding of identical sheets containing 0.22% C, a fracture in the base metal is thus observed when the ratio Z is greater than 1.108, that is to say when the hardness of the molten zone exceeds the hardness of the base metal by around 11%.

With reference to Fig. 7, the curves 47 and 48 show the change in the micro-hardness in the welded zone and in the zones neighbouring the welded zone shown on the respective micrographs M1 and M2, for a volume percentage of filler metal of 15% and for different thicknesses of welded sheets.

For the curve 47, relating to a cooling rate of 30°C per second, the micro-hardness measurements were carried out at the lateral edge of the molten zone, half-way along the thickness of the thinnest sheet, as shown in the micrograph M1 by the dotted line X1.

For the curve 48, relating to a cooling rate of 50°C per second, the micro-hardness measurements were carried out at the bottom of the welded zone, half-way along the thickness of the thinnest sheet, as shown in the micrograph M2 by the dotted line X2.

With reference to Fig. 8, the preferred limit conditions in terms of percentage of filler metal and welding speed for the specific composition of filler wire defined above and comprising a carbon content of 0.7% are defined by the hatched zone 50.

This zone 50 is delimited by four boundaries 51, 52, 53, 54.

The first boundary 51 defines the lower limit for the percentage of filler metal. The percentage of filler metal must thus be greater than 12% in order to prevent the welded zone from having mechanical strength characteristics that are too weak.

The second boundary 52 defines the upper limit for the percentage of filler metal. The percentage of filler metal must thus be less than 26% since, beyond this limit, the welded zone has a fragility that is incompatible with the required properties.

The third boundary 53 defines the lower limit for the welding speed. The welding speed must thus be greater than 3 metres per minute so as to obtain a satisfactory geometry of the weld bead and to avoid oxidation phenomena.

Finally, the fourth boundary 54 defines the upper limit for the welding speed and has a curved shape.

This fourth boundary 54 is defined on the basis of the experimental points 40, 41, 42 discussed above and for which the experimental points 42 correspond to specimens for which the mixing between the filler metal and the base metal is insufficient and/or the weld does not penetrate to a sufficient depth.

Furthermore, the curved shape of this fourth boundary 54 is estimated with regard to requirements specific to the welding operation.

This is because the ability of the laser source to melt the filler wire and to bring about a relatively homogeneous mixing has an influence on the maximum percentage of filler metal and on the welding speed.

To this end, for a welding speed of 4 metres per minute, for example, the percentage of filler metal will not be greater than around 25%.

For a higher welding speed, the proportion of filler metal will be limited.

In approximation of this fourth boundary 54, the equation of the straight line 55 passing through a first point 56 located at the junction between the upper part of the fourth boundary 54 and the second boundary 52, and through a second point 57 located at the junction between the lower part of the fourth boundary 54 and the first boundary 51 is estimated.

The equation of this straight line 55 is $Y=-3.86X+39.5$, where Y is the percentage of filler metal and X is the welding speed expressed in metres per minute.

It can thus be considered approximately that the fourth boundary defining the maximum limit for the welding speed is defined by the straight line 55 for a welding speed greater than 3.5 metres per minute.

The invention thus makes it possible to fabricate, in an economic manner, structural parts and safety parts for the automobile industry.

Patenttivaatimukset

1. Juotettu teräskappale, jolla on erittäin korkea mekaaninen lujuus ja joka on saatu kuumentamalla austeniittisella alueella, sitten lämpökäsittelyllä ja sen jälkeen jäähdyttämällä vähintään yksi juotettu aihio, joka on saatu juottamalla päittäin vähintään ensimmäinen ja toinen levy, jotka muodostuvat vähintään osittain terässubstraatista ja esipinnoitteesta, joka muodostuu teräs-substraatin kanssa kontaktissa olevasta intermetallisen seoksen kerroksesta, jonka päällä on alumiiniseoksesta tai alumiinipohjaisesta seoksesta muodostuva metalliseoskerros, tunnettu siitä, että ensimmäisen ja toisen levyn (11, 12) välisen liitoksen ja juottotoimenpiteestä saadun juotetun alueen (35) suorassa läheisyydessä olevat reunat (36) eivät käsitä metalliseoskerrosta (19, 20), samalla kun käsittävät intermetallisen seoksen kerroksen (17, 18), siitä, että hiilipitoisuuksien suhde vähintään osassa juotetun alueen (35) pituudesta ja korkeamman hiilipitoisuuden (Cmax) omaavan ensimmäisen tai toisen levyn (11, 12) substraatissa (25, 26) on 1,27 – 1,59 ja siitä, että vähintään ensimmäisen tai toisen levyn (11, 12) substraatin (25, 26) koostumus käsittää seuraavat pitoisuudet painoprosentteina:

0,10 % ≤ C ≤ 0,5 %
0,5 % ≤ Mn ≤ 3 %
0,1 % ≤ Si ≤ 1 %
0,01 % ≤ Cr ≤ 1 %
Ti ≤ 0,2 %
Al ≤ 0,1 %
S ≤ 0,05 %
P ≤ 0,1 %
0,0002 % ≤ B ≤ 0,010 %
lopun ollessa rautaa ja valmistuksesta syntyneitä epäpuhtauksia.

2. Patenttivaatimuksen 1 mukainen teräskappale, tunnettu siitä, että suhde (Z) juotetun alueen (35) lujuuden ja korkeamman hiilipitoisuuden (Cmax) omaavan ensimmäisen tai toisen levyn (11, 12) substraatin (25, 26) lujuuden välillä on suurempi kuin 1,029 + (0,36 Cmax), jolloin Cmax on ilmaistu painoprosentteina.

3. Jonkin patenttivaatimuksen 1 ja 2 mukainen teräskappale, tunnettu siitä, että vähintään ensimmäisen tai toisen levyn (11, 12) substraatin (25, 26) koostumus käsittää seuraavat pitoisuudet painoprosentteina:

0,15 % ≤ C ≤ 0,4 %

0,8 % ≤ Mn ≤ 2,3 %
0,1 % ≤ Si ≤ 0,35 %
0,01 % ≤ Cr ≤ 1 %
Ti ≤ 0,1 %
Al ≤ 0,1 %
S ≤ 0,03 %
P ≤ 0,05 %
0,0005 % ≤ B ≤ 0,010 %
lopun ollessa rautaa ja valmistuksesta syntyneitä epäpuhtauksia.

4. Jonkin patenttivaatimuksen 1 ja 2 mukainen teräskappale, tunnettu siitä, että vähintään ensimmäisen tai toisen levyn (11, 12) substraatin (25, 26) koostumus käsittää seuraavat pitoisuudet painoprosentteina:

0,15 % ≤ C ≤ 0,25 %
0,8 % ≤ Mn ≤ 1,8 %
0,1 % ≤ Si ≤ 0,35 %
0,01 % ≤ Cr ≤ 0,5 %
Ti ≤ 0,1 %
Al ≤ 0,1 %
S ≤ 0,05 %
P ≤ 0,1 %
0,0002 % ≤ B ≤ 0,005 %
lopun ollessa rautaa ja valmistuksesta syntyneitä epäpuhtauksia.

5. Jonkin edellisen patenttivaatimuksen mukainen teräskappale, tunnettu siitä, että juotetun alueen (35) hiilipitoisuus on pienempi tai yhtä suuri kuin 0,35 % painosta.

6. Jonkin edellisen patenttivaatimuksen mukainen teräskappale, tunnettu siitä, että esipinnoitteen (15, 16) metalliseoskerros (17, 18) käsittää seuraavat pitoisuudet painoprosentteina: 8 - 11 % piitä, 2 - 4 % rautaa, lopun koostumuksesta ollessa alumiinia ja väistämättömiä epäpuhtauksia.

7. Jonkin edellisen patenttivaatimuksen mukainen teräskappale, tunnettu siitä, että juotetun alueen (35) mikrorakenteessa ei ole ferriittiä.

8. Jonkin edellisen patenttivaatimuksen mukainen teräskappale, tunnettu siitä, että juotetun alueen (35) mikrorakenne on martensiittinen.

9. Jonkin edellisen patenttivaatimuksen mukainen teräskappale, tunnettu siitä, että juotetun levyn mainittu kuumamuokkaus toteutetaan syvävedolla kuumana.

10. Jonkin edellisen patenttivaatimuksen mukainen teräskappale, tunnettu siitä, että juotettaviksi tarkoitettujen ensimmäisen (11) ja toisen (12) levyn reuna-alueiden (21, 22) vastaavissa sivuissa (23, 24) ei ole alumiinia tai alumiiniseosta.

11. Menetelmä jonkin patenttivaatimuksen 1–10 mukaisen juotetun teräskappaleen valmistamiseksi, tunnettu siitä, että se käsittää seuraavat peräkkäiset vaiheet:

- hankitaan vähintään ensimmäinen (11) ja toinen (12) teräslevy, jotka muodostuvat terässubstraatista (25, 26) ja esipinnoitteesta (15, 16), joka muodostuu terässubstraatin kanssa kontaktissa olevasta intermetallisen seoksen kerroksesta (17, 18), jonka päällä on alumiiniseoksesta tai alumiinipohjaisesta seoksesta muodostuva metalliseoskerros (19, 20), ja siten että juotettaviksi tarkoitettujen ensimmäisen (11) ja toisen teräslevyn (12) reuna-alueen (21, 22) osasta vähintään yhdessä sivussa (13a, 13b; 14a, 14b) ei ole mainittua metalliseoskerrosta (19, 20) intermetallisen seoksen kerroksen (17, 18) jäädessä jäljelle, ja siten että juotettaviksi tarkoitettujen ensimmäisen (11) ja toisen (12) teräslevyn reuna-alueiden (21, 22) vastaavissa sivuissa (23, 24) ei ole alumiinia tai alumiiniseosta, jonka läsnäolo voi johtua kunkin ensimmäisen (11) ja toisen (12) levyn etukäteen tehdystä leikkauksesta, ja sen jälkeen

- juotetaan suojakaasun alla päittäin ensimmäinen (11) ja toinen (12) teräslevy näiden ensimmäisen (11) ja toisen (12) teräslevyn vastaavien reuna-alueiden (21, 22), joista metalliseoskerros (19, 20) puuttuu, tasolla laserjuottimen (30) avulla ja käyttämällä lisäainelankaa (32) vähintään osaan juotetun alueen pituudesta, juotelangan (32) käsittäessä suuremman hiilipitoisuuden kuin substraatin (25, 26) hiilipitoisuus vähintään toisessa kahdesta levystä (11, 12), jolloin koostumus on painoprosentteina ilmaistuna:

0.6% ≤ C ≤ 1.5%
1% ≤ Mn ≤ 4%
0.1% ≤ Si ≤ 0.6%
Cr ≤ 2%
Ti ≤ 0.2%

lopun ollessa rautaa ja valmistuksesta syntyneitä epäpuhtauksia, suojakaasu saadaan käyttämällä heliumia ja/tai argonia,

- saadaan juotettu sivu (37), jossa juottotoimenpiteestä saadun sulan alueen (35), joka muodostaa liitoksen ensimmäisen (11) ja toisen (12) levyn välillä, hiilipitoisuus on 1,27 - 1,59 kertaa sen levyn (11, 12) substraatin (25, 26) hiilipitoisuus, jonka hiilipitoisuus on suurempi, ja sen jälkeen

- lämmitetään mainittu juotettu sivu (37) siten, että sulalle alueelle (35) annetaan täysin austeniittinen rakenne, minkä jälkeen

- mainittu juotettu ja lämmitetty sivu kuumamuokataan, jotta saadaan teräskappale, minkä jälkeen

- mainittu teräskappale jäähdytetään kontrolloidulla nopeudella, jotta saadaan halutut mekaanisen lujuuden ominaisuudet,

ja siitä, että vähintään ensimmäisen tai toisen levyn (11, 12) substraatin (25, 26) koostumus käsittää seuraavat pitoisuudet painoprosentteina:

0,10 % ≤ C ≤ 0,5 %
0,5 % ≤ Mn ≤ 3 %
0,1 % ≤ Si ≤ 1 %
0,01 % ≤ Cr ≤ 1 %
Ti ≤ 0,2 %
Al ≤ 0,1 %
S ≤ 0,05 %
P ≤ 0,1 %
0,0002 % ≤ B ≤ 0,010 %
lopun ollessa rautaa ja valmistuksesta syntyneitä epäpuhtauksia.

12. Patenttivaatimuksen 11 mukainen menetelmä, tunnettu siitä, että ensimmäisen (11) ja toisen (11, 12) teräslevyn vastaavien reuna-alueiden (21, 22) vastakkaisissa sivuissa (13a, 13b, 14a, 14b) ei ole metalliseoskerrosta (19, 20) intermetallisen seoskerroksen (17, 18) jäädessä jäljelle.

13. Jonkin patenttivaatimuksen 11 ja 12 mukainen menetelmä, tunnettu siitä, että sen alueen leveys, jossa ei ole metalliseoskerrosta (19, 20) juotettavaksi tarkoitettujen ensimmäisen (11) ja toisen (12) levyn reuna-alueilla (21, 22), on 0,2 - 2,2 millimetriä.

14. Jonkin patenttivaatimuksen 11–13 mukainen menetelmä, tunnettu siitä, että vähintään ensimmäisen tai toisen levyn (11, 12) substraatin (25, 26) koostumus käsittää seuraavat pitoisuudet painoprosentteina:

0,15 % ≤ C ≤ 0,4 %
0,8 % ≤ Mn ≤ 2,3 %
0,1 % ≤ Si ≤ 0,35 %
0,01 % ≤ Cr ≤ 1 %
Ti ≤ 0,1 %

Al ≤ 0,1 %
S ≤ 0,03 %
P ≤ 0,05 %
0,0005 % ≤ B ≤ 0,010 %
lopun ollessa rautaa ja valmistuksesta syntyneitä epäpuhtauksia.

15. Patenttivaatimuksen 13 mukainen menetelmä, tunnettu siitä, että vähintään ensimmäisen tai toisen levyn (11, 12) substraatin (25, 26) koostumus käsittää seuraavat pitoisuudet painoprosentteina:

0,15 % ≤ C ≤ 0,25 %
0,8 % ≤ Mn ≤ 1,8 %
0,1 % ≤ Si ≤ 0,35 %
0,01 % ≤ Cr ≤ 0,5 %
Ti ≤ 0,1 %
Al ≤ 0,1 %
S ≤ 0,05 %
P ≤ 0,1 %
0,0002 % ≤ B ≤ 0,005 %
lopun ollessa rautaa ja valmistuksesta syntyneitä epäpuhtauksia.

16. Jonkin patenttivaatimuksen 11–15 mukainen menetelmä, tunnettu siitä, että ensimmäisen (11) ja toisen (12) levyn juotettavat reuna-alueet (21, 22) on asetettu juoton aikana enintään 0,1 millimetrin etäisyydelle toisistaan.

17. Jonkin patenttivaatimuksen 11–16 mukainen menetelmä, tunnettu siitä, että mainitun laserlähteen juoton lineaarinen energia juottotoimenpiteen aikana on suurempi kuin 0,3 kJ/cm.

18. Patenttivaatimuksen 17 mukainen menetelmä, tunnettu siitä, että laserlähde on joko tyyppiä CO_2, kaasulaser, joka antaa yli 1,4 kJ/cm:n lineaarisen juottoenergian, tai tyyppiä kiinteän olomuodon laser, joka antaa yli 0,3 kJ/cm:n lineaarisen juottoenergian.

19. Jonkin patenttivaatimuksen 17 ja 18 mukainen menetelmä, tunnettu siitä, että juottonopeus on 3–8 metriä sekunnissa ja siitä, että CO_2 kaasulaserin teho on suurempi tai yhtä suuri kuin 7 kW ja kiinteän olomuodon laserin teho on suurempi tai yhtä suuri kuin 4 kW.

20. Jonkin patenttivaatimuksen 11–19 mukainen menetelmä, tunnettu siitä, että juotto toteutetaan helium- ja/tai argonkaasun alla.

21. Patenttivaatimuksen 20 mukainen menetelmä, tunnettu siitä, että helium- ja/tai argonkaasun virtaus on juottotoimenpiteen aikana suurempi tai yhtä suuri kuin 15 litraa minuutissa.

22. Jonkin patenttivaatimuksen 11–21 mukainen menetelmä tunnettu siitä, että lisäainelanka käsittää seuraavat pitoisuudet painoprosentteina:

$0{,}65\ \% \leq C \leq 0{,}75\ \%$

$1{,}95\ \% \leq Mn \leq 2{,}05\ \%$

$0{,}35\ \% \leq Si \leq 0{,}45\ \%$

$0{,}95\ \% \leq Cr \leq 1{,}05\ \%$

$0{,}15\ \% \leq Ti \leq 0{,}25\ \%$

lopun ollessa rautaa ja valmistuksesta syntyneitä epäpuhtauksia.

23. Patenttivaatimuksen 22 mukainen menetelmä tunnettu siitä, että lisämetallin osuus suhteessa sulan alueen (35) tilavuuteen on 12 - 16 % ja siitä, että juottonopeus on 3 - 7 metriä minuutissa.

24. Patenttivaatimuksen 23 mukainen menetelmä tunnettu siitä, että mainitun lisämetallin osuuden muodostama lujuusmomentti suhteessa sulan alueen (35) tilavuuteen, sekä juottonopeus sijoittuvat kuviossa 8 esitetylle alueelle (50).

25. Patenttivaatimuksen 24 mukainen menetelmä tunnettu siitä, että mainitun lisämetallin osuuden muodostama lujuusmomentti suhteessa sulan alueen (35) tilavuuteen sekä juottonopeus vastaavat seuraavia yhdistettyjä vaatimuksia:

- lisämetallin osuus suhteessa sulan alueen (35) tilavuuteen on 12 - 26 %, ja

- juottonopeus on 3 - 7 metriä minuutissa,

ja

- kun juottonopeus on suurempi kuin 3,5 metriä minuutissa, yhtälö, joka muodostuu lisämetallin osuudesta suhteessa sulan alueen (35) tilavuuteen ja juottonopeudesta on $Y \leq -3{,}86X+39{,}5$, jolloin Y on lisämetallin osuus tilavuusprosentteina ja X on juottonopeus metreinä minuutissa.

26. Jonkin patenttivaatimuksen 23–25 mukainen menetelmä, tunnettu siitä, että lisämetallin osuus suhteessa sulan alueen (35) tilavuuteen, on 14 - 16 %, helium- ja/tai argonvirran virtaus 13 - 17 litraa minuutissa, siitä, että lasersädekimpun (30) vaikutuskohta levyyn on halkaisijaltaan 500 - 700

mikrometriä ja siitä, että lisäainelangan (32) pääty (32a) sijaitsee 2 - 3 millimetrin etäisyydellä lasersädekimpun vaikutuskohdasta levyssä.

27. Jonkin patenttivaatimuksen 11–26 mukainen menetelmä, tunnettu siitä, että sulan alueen (35) jäähtymisnopeus kuumamuokkausvaiheen aikana on suurempi tai yhtä suuri kuin mainitun sulan alueen (35) martensiittisen karkaisun kriittinen nopeus.

28. Jonkin patenttivaatimuksen 1–10 mukaisen teräskappaleen käyttö etenkin autoja varten tarkoitettujen rakenne- tai turvaosien valmistuksessa.

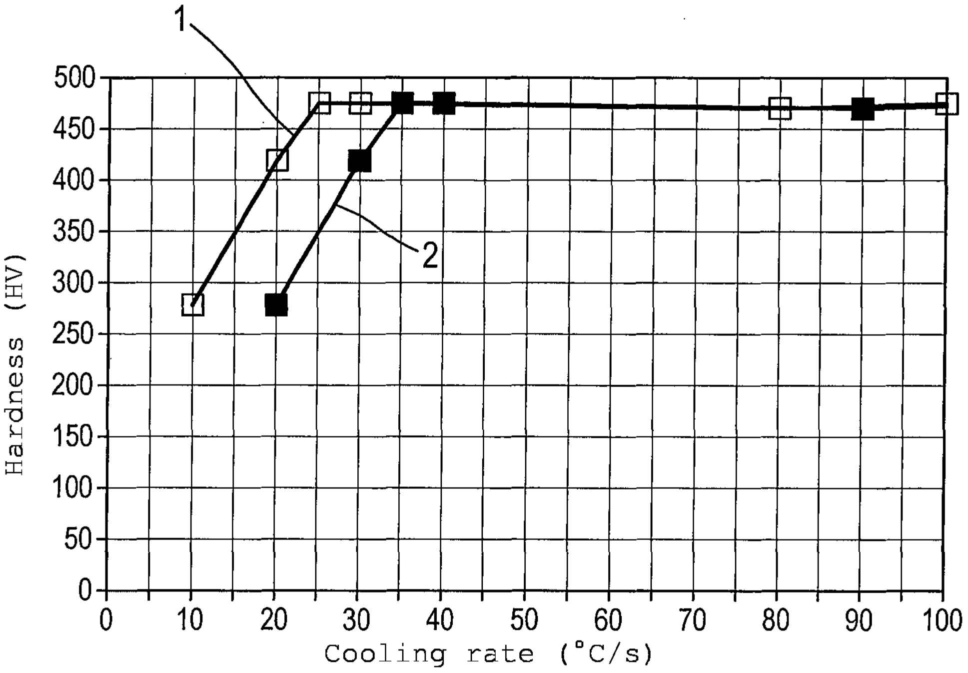

1
2
Hardness (HV)
500
450
400
350
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
Cooling rate (°C/s)

FIG. 1

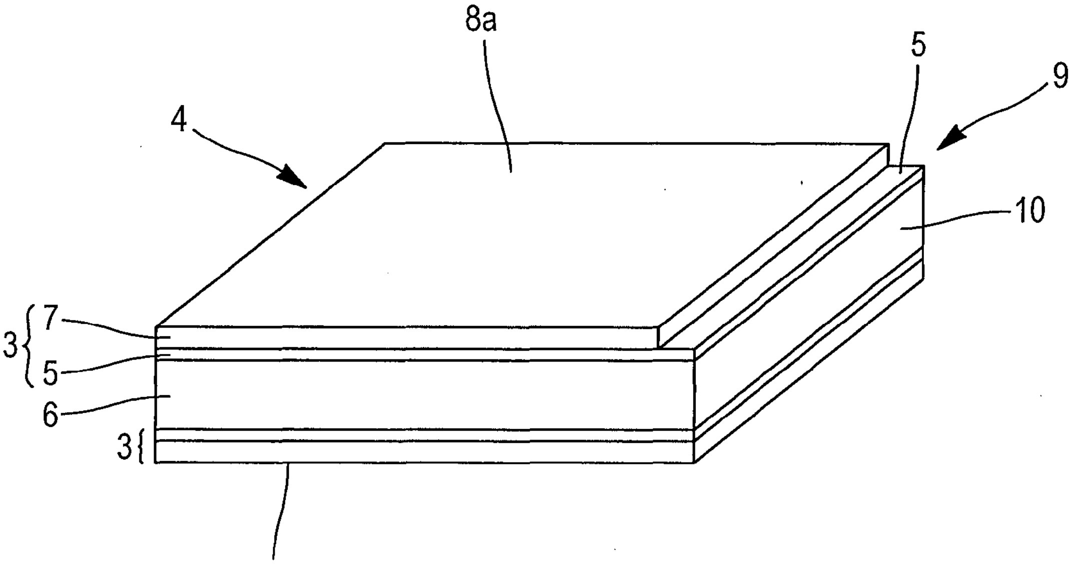

8a
5
9
4
10
3
7
5
6
3
8b

FIG. 2

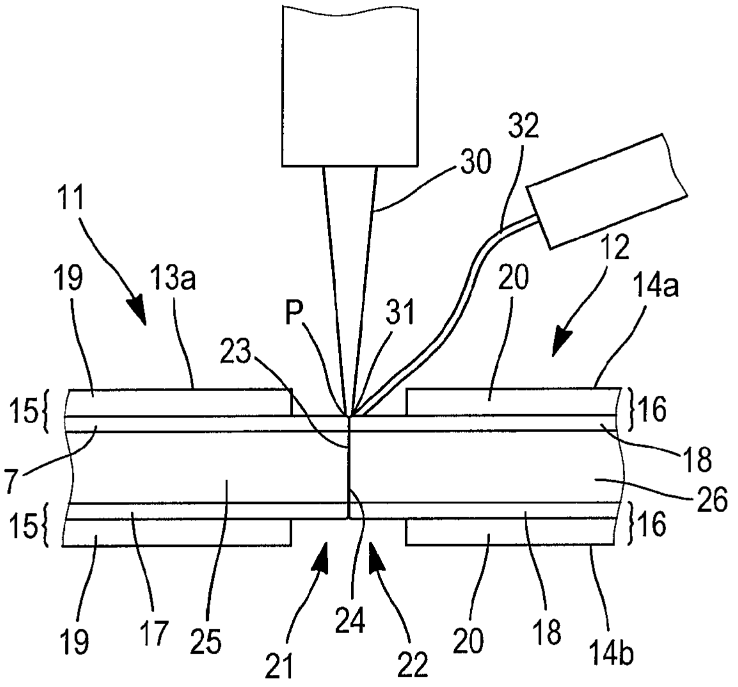

32
30
11
12
19
13a
20
14a
P
31
23
15
16
17
18
26
15
16
19
17
25
24
20
18
14b
21
22

FIG. 3

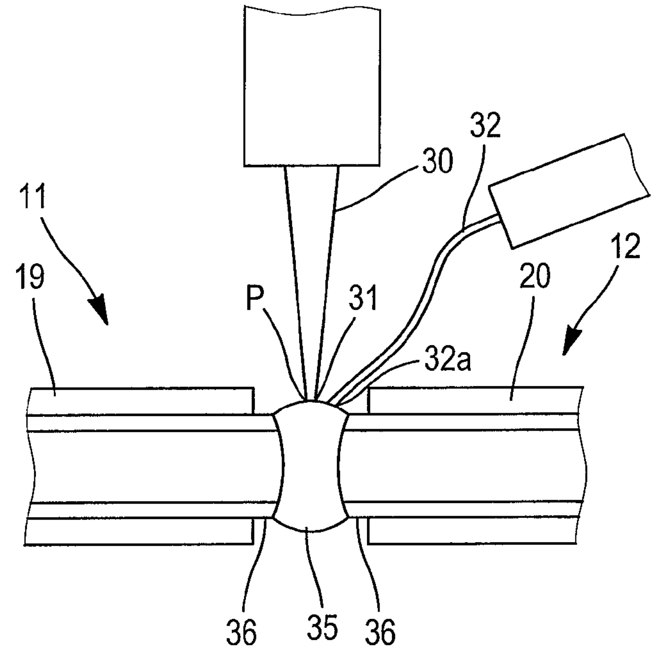
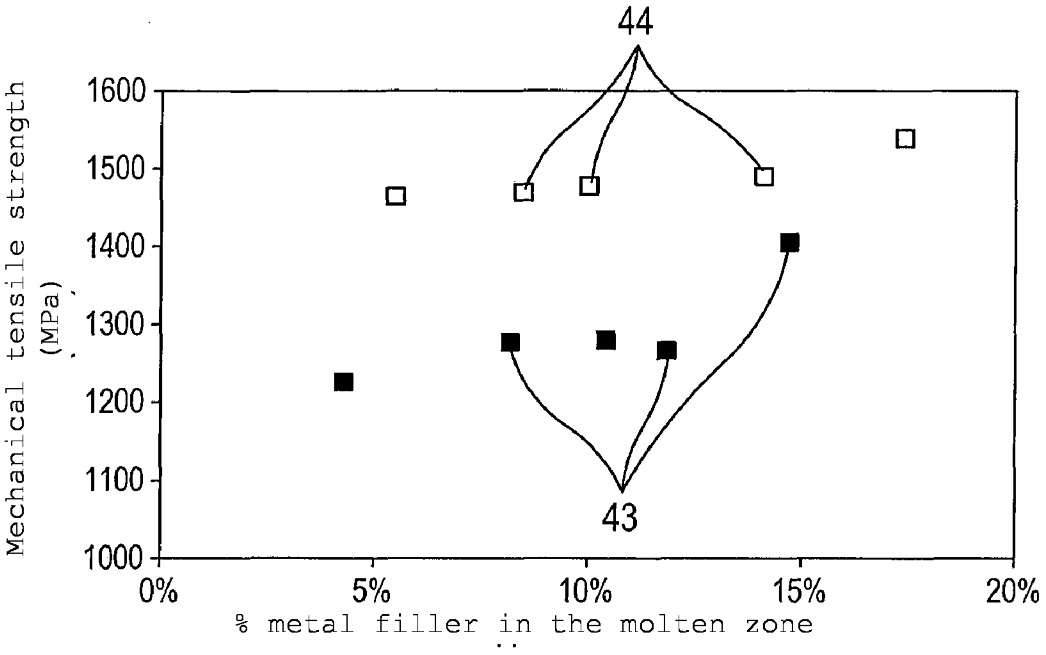
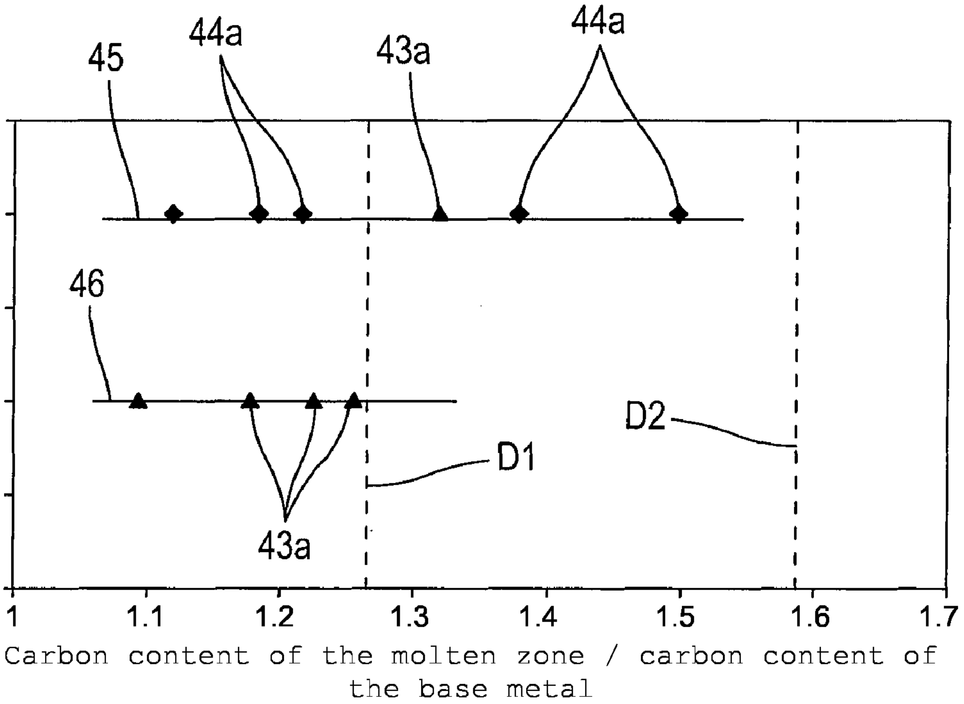

32
30
11
12
19
20
P
31
32a
36
35
36

FIG. 4



44
Mechanical tensile strength (MPa)
1600
1500
1400
1300
1200
1100
1000
43
0%
5%
10%
15%
20%
% metal filler in the molten zone

FIG. 5



45
44a
43a
44a
46
D2
D1
43a
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
Carbon content of the molten zone / carbon content of the base metal

FIG. 6

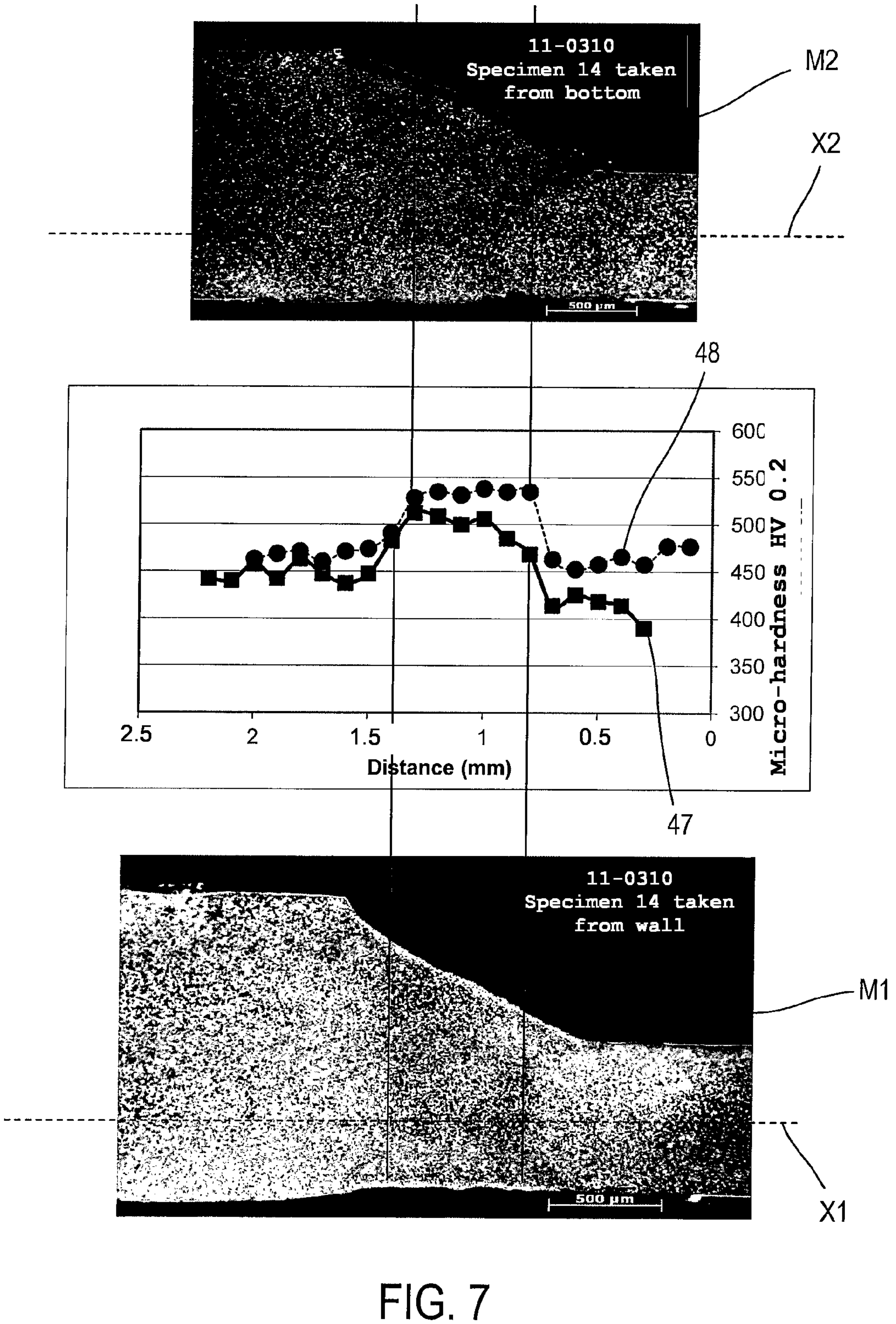
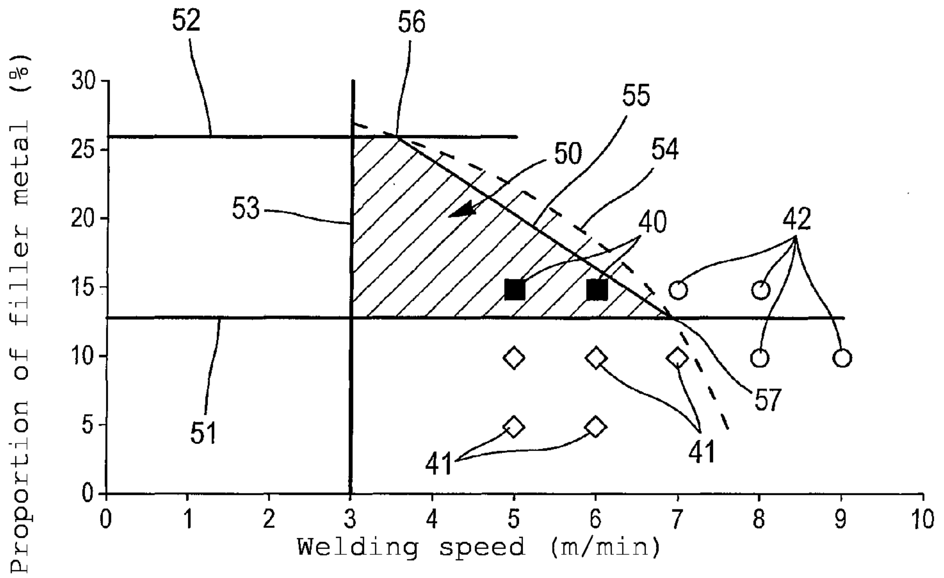
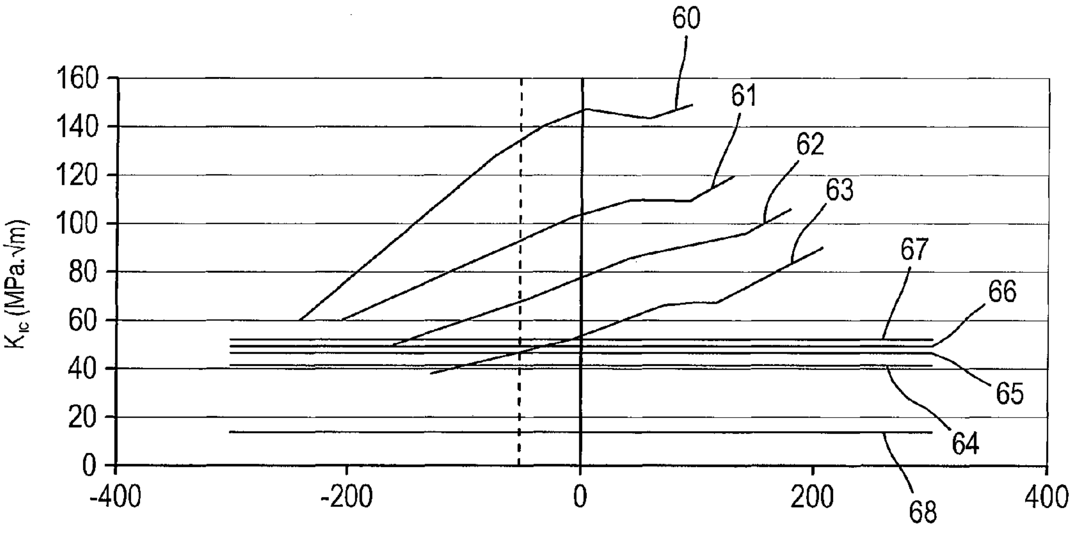
11-0310
Specimen 14 taken
from bottom
500 µm
M2
X2
48
600
550
500
450
400
350
300
2.5
2
1.5
1
0.5
0
Distance (mm)
Micro-hardness HV 0.2
47
11-0310
Specimen 14 taken
from wall
500 µm
M1
X1

FIG. 7



52
56
55
50
54
53
40
42
57
51
41
41
Proportion of filler metal (%)
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
Welding speed (m/min)

FIG. 8



60
61
62
63
67
66
65
64
68
K_{Ic} (MPa.√m)
160
140
120
100
80
60
40
20
0
-400
-200
0
200
400
Temperature (°C)

FIG. 9