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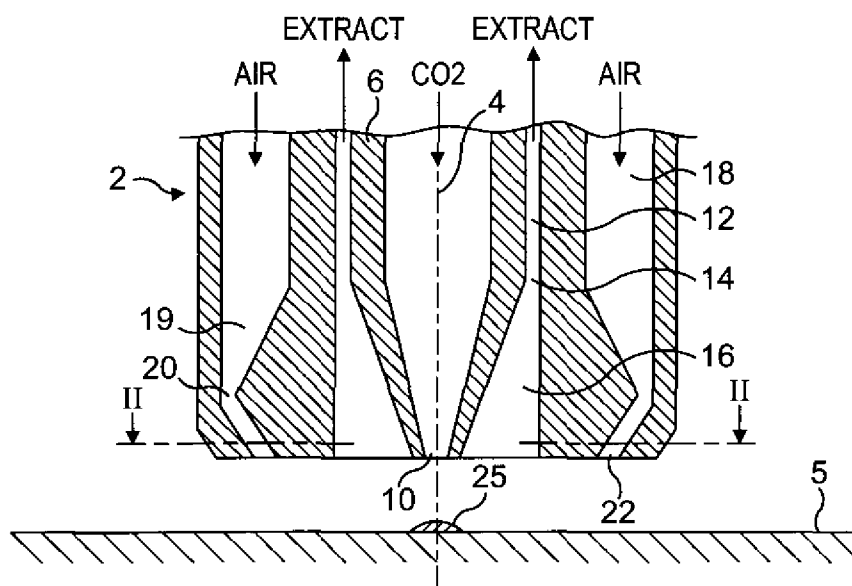
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(54) Title: WELD COOLING



(57) Abstract: A heated weld zone (25) on work being welded is forcedly cooled by directing a jet of cryogenic coolant from a nozzle (6) at the heated weld zone (25). Resulting vapour of the cryogenic coolant is extracted through a first passage (12) from a vapour space (16) surrounding the distal end of the nozzle (6), which vapour space (16) is open to the atmosphere. A jet of auxiliary gas is directed through a second passage (18) to an outlet (22) from which it is ejected towards a region of the surface area of the work adjacent the heated weld zone (25). The auxiliary gas limits escape of the vapour along the surface of the work.

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WELD COOLING

The present invention relates to apparatus for and a method of forced cooling of a heated weld zone by directing a jet of cryogenic coolant at the weld zone.

5

During the thermal welding of metallic workpieces a high heat input is required to generate an acceptable weld. However, this high heat input has a disadvantage that the thermal stresses generated by the welding process can cause significant levels of distortion of the workpieces being welded. Sheet
10 workpieces of relatively soft metals and alloys such as mild steel, titanium, titanium alloys and stainless steels are particularly prone to distortion and reduced tensile strength.

It is known to use a jet of cryogen, particularly carbon dioxide, to provide
15 cooling to thermal joining processes (including solid phase welding, for example, friction stir welding), particularly arc welding processes, so as to reduce or eliminate distortion or to modify the microstructure of the weld metal. The cryogenic coolant extracts heat from the workpieces and is vaporised or sublimed as a result. There therefore tends to be a build up of
20 vaporised coolant which, if unchecked, can be hazardous to the welder.

According to the present invention there is provided apparatus for the forced cooling of a heated weld zone in work being welded, the apparatus comprising at least one nozzle for ejecting at least one jet of a cryogenic
25 coolant at the heated weld zone, a first passage for the extraction of vapour of the cryogenic coolant having a mouth communicating with a vapour space in the vicinity of the said nozzle but outside the path of flow of the said jet of cryogenic coolant from the said nozzle to the heated weld zone, the vapour space being open to the atmosphere outside the apparatus, and at least one
30 second passage terminating in at least one outlet for ejecting at least one jet of auxiliary gas towards a region of the surface area of the work adjacent to the heated weld zone so as to cause the vapour of the cryogenic coolant to

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pass into the said vapour space, from where it can be extracted through the first passage, and to limit escape of the vapour of the cryogenic coolant along the surface of the work.

- 5 The invention also provides a method of forced cooling of a heated weld zone in work being welded, the method comprising directing at least one jet of cryogenic coolant at the heated weld zone, extracting vapour of the cryogenic coolant from a vapour space in the vicinity of but outside the path of flow of the said jet of cryogenic coolant to the heated weld zone, the vapour space
10 being open to the atmosphere, and directing at least one jet of auxiliary gas towards a region of the surface area of the work adjacent to the heated weld zone, the said jet of auxiliary gas causing passage of vapour of the cryogenic coolant into the said vapour space and limiting escape of the vapour of the cryogenic coolant along the surface of the work.

15

The terms "welding" and "weld" as used herein refer to any thermal joining method.

- The auxiliary gas is normally air. In this case, an advantage of the method
20 and apparatus according to the invention is that they can be operated without substantial risk of the vapour of the cryogenic coolant concentrating in the atmosphere experienced by the welder and reaching a hazardous level. In particular, the said jet of auxiliary gas counteracts the tendency for the vapour of the cryogenic coolant to form a strong flow away from the weld along the
25 surface of the work being welded. Further, the method and apparatus according to the invention do not employ an extraction hood surrounding the nozzle of a kind in which the hood has sealing surfaces which engage the work and in which the hood completely overlaps the nozzle, thereby interfering unduly with the welder's line of sight. The apparatus according to
30 the invention can be made sufficiently small not significantly to impede the line of sight of the welder.

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The apparatus according to the invention is typically arranged to be moved over the weld relative to the work. The apparatus according to the invention by therefore be mounted on a suitable carriage.

5 The apparatus according to the invention may have a number of different configurations. For example, the first passage may have an endless mouth surrounding the nozzle. The endless mouth may be in the form of an annular slot. The annular slot may be coaxial with the nozzle. In such an embodiment, the outlet of the second passage may also be endless and
10 surround the mouth of the first passage. Similarly, the outlet of the second passage may be in the form of an annular slot. Preferably, in such an embodiment the said outlet of the second passage has a configuration so as, in use, to provide the auxiliary gas as it exits the said outlet with a radial component of velocity. For example, the outlet of the second passage may
15 have a configuration so as, in use, to direct the jet of auxiliary gas inwards at an angle in the range of 10° to 60° to the surface of flat work being welded. Preferably in such an embodiment, the nozzle is configured so as, in use, to direct the jet of cryogenic coolant normally to the surface of flat work being welded. If desired, the nozzle, first passage and second passage may all be
20 provided in a single head. In an alternative embodiment of the apparatus according to the invention the nozzle and the first passage are provided in a single head, but the second passage is defined in a separate member. Nonetheless, the head and the separate member may be arranged to move as a unit along the weld.

25

If desired, the outlet of the second passage need not extend forwardly of the nozzle in the direction of its travel relative to the work. In electric arc welding, such an arrangement minimises the risk of the air interfering with the welding arc. For example, significant penetration of air, if this is the auxiliary gas,
30 might extinguish the arc. However, even if a part of the auxiliary gas leads the jet of cryogenic coolant, risk of the air adversely affecting the welding arc can be easily eliminated by positioning the apparatus according to the

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invention sufficiently behind the welding torch. In such a case the extent of the outlet of the second passage will simply be determined by the pattern of spread of the vapour of the cryogenic coolant along the surface of the work, but will typically not exceed an angle of 270° . In such configurations both the
5 mouth of the first passage and the outlet of the second passage may be arcuate or horse shoe shaped and situated rearwardly of the nozzle.

Rather than have the nozzle direct the cryogenic coolant normally to the weld zone, the nozzle may have a configuration such that in use it directs the jet of
10 cryogenic coolant rearwardly in relation to the direction of motion of the apparatus according to the invention relative to the weld zone. Such an arrangement enables the nozzle to be mounted quite close to a welding torch used to deposit the weld metal. The outlet of the second passage typically then has a configuration to impart to the jet of auxiliary gas a forward or
15 inward component of velocity.

Instead of being continuous, the outlet of the second passage may comprise a multiplicity of spaced apart orifices.

20 The cryogenic coolant may be any substance having a temperature of minus 50°C or less which is gaseous or vaporous at ambient temperatures, and is preferably solid carbon dioxide. A jet of particles of solid carbon dioxide can be formed by passing a stream of liquid carbon dioxide at a pressure above its critical pressure through the nozzle. A particular advantage of solid carbon
25 dioxide is that it can collect on the surface of the heated weld zone and take its enthalpy of sublimation from the heated weld zone. The stand-off distance of the nozzle from the heated weld zone is typically in the order of 30 to 50mm. The nozzle itself typically has a relatively small internal radius, for example, of 1.2mm. The apparatus according to the invention is preferably
30 mounted on a carriage which is adapted to track the weld.

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The nozzle is preferably adapted to eject the cryogenic coolant at a supersonic velocity.

5 The method and apparatus according to the invention is suitable for use in conjunction with conventional arc welding methods, such as MIG welding, TIG welding and plasma arc. They may also be used to provide cooling to any other thermal joining process, including solid phase welding (FSW), for example friction stir welding, so as to reduce or eliminate distortion or to modify the microstructure of the weld metal.

10

The method and apparatus according to the invention will now be described by way of example with reference to the accompanying drawings, in which:

15 Figure 1 is a schematic sectional side elevation of a first weld cooling apparatus according to the invention;

Figure 2 is a section through the line I-I of Figure 1;

20 Figure 3 is a section similar to Figure 2 showing an alternative embodiment of the apparatus shown in Figures 2 and 3;

Figure 4 is a schematic sectional side elevation of a further alternative apparatus according to the invention;

25 Figure 5 is a schematic view from below of the apparatus shown in Figure 4; and

Figure 6 is a similar view to Figure 5 showing a modification to the apparatus illustrated in Figures 4 and 5.

30

Referring to Figures 1 and 2 of the drawings, a cooling head 2 is symmetrical about its longitudinal axis 4 and located above work 5 to be welded. The

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head 2 is mounted on a carriage (not shown) behind an arc welding torch (not shown). The head 2 comprises a central nozzle 6 which is coaxial with the axis of the head 2. The nozzle 6 has a distal end portion which tapers to an orifice 10 through which in use the jet of cryogenic coolant is ejected. An
5 annular first passage 12 in the head 2 for the extraction of vapour of the cryogenic coolant surrounds and is coaxial with the nozzle 6. The first passage 12 has a mouth 14 generally level with the start of the taper of the nozzle 6. Beneath the mouth 14 there is a space 16 round the tapering distal
10 portion 8 of the nozzle 6. In operation of the cooling head shown in Figures 1 and 2, vapour of the cryogenic coolant tends to collect in the space 16 and is extracted through the first passage 12.

An annular second passage 18 surrounds the annular first passage 12 and is coaxial therewith. The proximal end of the annular second passage 18 is
15 coaxial with the nozzle 6. The passage 18 has an intermediate portion 19 that tapers on one side to a waist 20 and terminates downstream of the waist in an annular outlet 22 which is arranged so as, in use, to direct an auxiliary gas inwardly. In operation, the arc welding torch (not shown) and the head 2 are
20 moved in unison over the work 5, with the head 2 lagging the arc welding torch. A heated weld zone 25 is formed by the deposition of weld metal from the arc welding torch on to the work 5. A stream of liquid carbon dioxide, or other cryogenic coolant, under pressure, (typically in the range of 15 to 25 bar) is passed from a source thereof (not shown) to the head 2.

25 As the liquid carbon dioxide passes through the outlet orifice 10 of the nozzle 6, so it is converted into a jet of gas carrying particles of solid carbon dioxide. This jet deposits solid carbon dioxide on the heated weld zone 25 as the head 2 follows the welding torch (not shown). The cooling region is typically
between 10 and 60mm behind the welding arc, for example from 20 to 30mm.

30

The liquid carbon dioxide is supplied at a pressure such that solid carbon dioxide will not be formed until the pressure is released as a consequence of

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the ejection of the carbon dioxide through the orifice 10 of the nozzle 6. The nozzle 6 is arranged to eject the pressurised stream of carbon dioxide at a high, preferably supersonic, velocity. Accordingly, the nozzle is preferably a Laval nozzle which has a characteristic convergent-divergent bore at its distal end. It is as the liquid carbon dioxide is expanded rapidly in the divergent section of the Laval nozzle that a part of it solidifies. At optimal conditions about 40% is converted to solid and the rest to gas. The solid particles are accelerated by the gaseous component. One advantage of employing a high velocity jet of cryogenic coolant is that it has the momentum necessary to penetrate any blanket of vapour that forms in operation over the heated welded zone 25. A particular advantage of the use of liquid carbon dioxide as the cryogenic coolant is that at least a part of the solid carbon dioxide that is formed by passage through the nozzle 6 collects on the surface of the work and extracts heat therefrom on change of state. The acceleration of the solid particles in the Laval nozzle facilitates their deposition on the work.

The welding head is in operation positioned quite close the work 5 being welded. Typically, a stand off position of from 30 to 50mm from the heated weld zone 25 is used. An advantage of such a relatively short stand-off distance is that the jet of cryogenic coolant issuing from the nozzle 6 diverges and loses momentum only to a limited extent.

We have found that if a jet of cryogen is simply directed at the heated weld zone 25, there tends to be established a flow regime in which there is a strong radially outward flow of vapour of the cryogen along the surface of the work being welded. Because of this radial flow the mere application of suction around the exterior of the nozzle is insufficient to effect satisfactory extraction of the vapour of the cryogenic coolant. One solution to this problem outside the scope of the invention would be to provide the nozzle with a hood which makes a sealing engagement with the surface of the work being welded. However, motion of the weld cooling head relative to the work would make it difficult to achieve satisfactory, durable, sealing of the hood to the work.

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Further, such a hood would tend to impede the welder's sight of the welding arc. In accordance with the invention, however, ejection of an annular, laminar jet of air (or other auxiliary gas) from the outlet 22 of the auxiliary gas passage 18 has the effect of curtailing the escape of coolant vapour along the surface of the work 5 to be welded, and helps to create a flow regime in which the spent vapour of the cryogenic coolant tends even without the application of suction to collect in the space 16 around the distal end 8 of the nozzle 6 so that it can be readily extracted by the application of a suitable suction to the proximal end of the extraction passage 12. Any suitable known extraction device such as an extraction fan (not shown) may be used for this purpose. We believe that the effect of the auxiliary jet is to create a flow of auxiliary gas along the work in the opposite direction to the flow along the work of the vapour of the cryogenic coolant. Once the two flows meet the gas can pass only upwards into the vapour space 16.

The jet of air issues from the outlet 22 of the passage 18 in the form of an annular, laminar, sheet. The air is typically supplied from a source of compressed air at a pressure typically in the range of 2 bar to 10 bar. The pressure is sufficient for the air to issue from the outlet 22 of the passage 18 with an appreciable velocity, typically approaching sonic velocity, i.e. as an air knife. The jet of air is directed at a region of the surface of the work spaced from the region impinged upon by the cryogenic coolant. The velocity of the air is such that it is deflected on impact against the surface of the work into the space 16 from which vapour is readily extracted through the extraction passage 12. The surface area impacted by the air jet is therefore not so remote from the heated weld zone 25 from that simultaneously impacted by the cryogenic coolant that extraction of the deflected air is not satisfactorily effected. On the other hand the surface area impacted by the air jet is not so close to that simultaneously impacted by the cryogenic coolant that the air interferes with the weld cooling.

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The inward angle at which the air jet issues from the outlet 22 is not critical. In radial cross-section this angle is typically in the range from 30 to 80° relative to the longitudinal axis of the nozzle 6. We believe, however, that the opposed flows of cryogenic coolant vapour (carbon dioxide) and auxiliary gas (air) desirably have equal mass flow rates where they meet. The angle of incidence of the air jet, its pressure and the size of the outlet 22 of the second passage 18 all affect the local mass flow rate of the auxiliary gas. If the air jet is too perpendicular to the work then some of the air will be deflected away from the carbon dioxide thus reducing the flow along the work towards the carbon dioxide. In consequence, the air flow to the passage 18 has to be sufficiently large to compensate for this loss. There is however no limit to how shallow the air jet is provided the air flow impacts the work at a suitable distance from the carbon dioxide jet and provided the carbon dioxide does not escape beneath the air. If the air jet impact is too close to the carbon dioxide it will reduce the cooling efficiency as the air is relatively warm. Particularly shallow angles are therefore not preferred.

In operation, as discussed above the rate of mass flow of the air is typically approximately equal to the rate of mass flow of the cryogenic coolant. The latter flow rate is dictated by the rate at which it is desired to cool the weld in order to prevent distortion or to bring about a desired metallurgical change to the microstructure of the resulting weld metal.

The apparatus shown in Figures 1 and 2 is open to the surrounding atmosphere and is not confined within any hood or the like. The vapour space 16 thus communicates with the open atmosphere.

One particular modification that can be made to the apparatus shown in Figures 1 and 2 is illustrated in Figure 3. Instead of having an annular outlet 22 the passage 18 has an outlet in the form of a ring of orifices 40. The spacing of the orifices 40 is sufficiently close that a continuous laminar sheet of air is formed rather than an array of individual pencil-like jets. In all other

- 10 -

respects, the apparatus shown in Figure 3 is essentially identical to that shown in Figures 1 and 2 and its operation is substantially the same.

If desired, a forward part of the annular outlet 22 may be blasted off so that the most forward part of the air jet produced by the apparatus shown in Figures 1 and 2 is eliminated. Typically, at least the most forward quarter of the annular outlet 22 is blanked off. The mouth 14 of the extraction passage 12 may similarly be curtailed.

Even though the apparatus according to the invention may be arranged such that the heated weld zone encounters the cryogenic coolant before the air jet there needs to be a sizeable gap between the welding torch and the weld cooling apparatus such that, in use, the cryogenic coolant does not encounter molten weld metal. The embodiment of the apparatus shown in Figures 4 and 5 is able to reduce this gap and has a nozzle 50 for the ejection of a cryogenic coolant which defines at its proximal end a passage 52 that tapers to a waist 54. Downstream of the waist 54 the passage 52 is inclined rearwardly, that is away from the direction of travel of the apparatus relative to work 60 being welded, and terminates at its distal end in an orifice 56. As a result, a jet of cryogenic coolant issues rearwardly from the orifice 56. The jet, in use of the apparatus, impinges upon the heated weld zone 75 and thereby provides cooling for it. Solid carbon dioxide gathers on the surface of the heated weld region and sublimates. The resulting vapour passes into a vapour space 70 communicating with the open atmosphere. Typically the rearward surface 72 of the nozzle 50 is curved and helps to guide the carbon dioxide vapour from the vapour space 70 into generally semi-circular mouth 74 of a rearward fume extraction passage 76. The nozzle 50 and the passage 76 are typically provided by a one-piece head 78.

Separate from the head 78 there is a secondary passage or nozzle 80 for directing air at the work being welded. The passage 80 ends in a generally semi-circular or arcuate outlet 82. In operation, a jet of air issues from the

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outlet 82 in the form of a curved, laminar, "sheet". The air is typically supplied from a source of compressed air at a pressure typically in the range of 2 to 10 bar. The pressure is sufficient for the air to issue from the outlet 82 of the passage 80 with an appreciable velocity, typically approaching sonic velocity.

- 5 The jet of air is directed at a region of the surface of the work spaced from the region impinged upon by the cryogenic coolant. As described with reference to Figures 1 and 2, there is created a flow of air along the work which opposes and equals the flow of carbon dioxide along the work. As a result carbon dioxide is caused to flow into the vapour space 70 from which the vapour is
- 10 readily extracted through the passage 80. The surface area of the work impacted by the air jet is therefore not so remote from that simultaneously impacted by the cryogenic coolant that extraction of the air through the passage 80 is not satisfactorily effected. On the other hand, the surface area impacted by the air jet is not so close to that simultaneously impacted by the
- 15 cryogenic coolant that the air interferes with the jet of cryogenic coolant or significantly reduces its cooling efficiency.

The outlet 82 is typically in the form of an arcuate or horseshoe-shaped slot. The arc may typically subtend an angle in the order of 80° or greater.

- 20 Because the jet of carbon dioxide has a rearward component of velocity, the bulk of the flow of carbon dioxide vapour tends to be rearward. If desired a rearward region of the outlet 82 can be made wider than more lateral regions so as to give a pattern of air flow that matches the flow of the carbon dioxide.

- 25 The outlet 82 is configured such that the air jet issues with a forward component of velocity, that is a component of velocity in the direction of the movement of the cooling apparatus relative to the work. This angle is not critical and may be selected taking into account the factors discussed above with reference to Figures 1 and 2 of the drawings in relation to the angling of
- 30 the outlet 22.

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The head 78 and the nozzle 80 are typically mounted to a common carriage (not shown) with an arc welding torch (not shown) so that they can be moved in unison relative to the work.

- 5 The gas collecting the vapour space 70 is withdrawn by applying a suction to the proximal end of the extraction passage 70.

It is an advantage of the apparatus shown in Figures 4 and 5 that it does not significantly obstruct the welder's view of the welding arc. For example, the
10 head 78 may have a diameter of 25mm or less.

In operation, the flow of the air is typically in the same order of magnitude as the rate of flow of the cryogenic coolant. The latter flow rate is dictated by the rate at which it is desired to cool the weld in order to prevent distortion or to
15 bring about a desired metallurgical change to the microstructure of the weld metal. A fan or pump (not shown) is operated so as to extract gas from the region 70 at a rate which ensures that there is no substantial loss of carbon dioxide from the region 70 into the surrounding atmosphere.

- 20 Referring now to Figure 6 of the drawings, instead of having a single arcuate, semi-circular or horse shoe shaped outlet, the passage or nozzle 80 now has an array of outlet orifices 88 which are spaced on an arc, semi-circle or horse shoe shape. The spacing of the orifices 88 is sufficiently close that a continuous laminar sheet of air is formed rather than an array of individual
25 pencil-like jets. If desired, the most rearward orifices 88 may be larger than the others for the same reasons as given above in relation to the choice of wider rearward dimensions for the aperture 82 in the apparatus shown in Figures 4 and 5. In all other respects, the apparatus shown in Figure 6 is essentially identical to that shown in Figures 4 and 5 and its operation is
30 substantially the same.

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CLAIMS

1. Apparatus for the forced cooling of a heated weld zone in work being welded, the apparatus comprising at least one nozzle for ejecting at least one jet of a cryogenic coolant at the heated weld zone, a first passage for the extraction of vapour of the cryogenic coolant having a mouth communicating with a vapour space in the vicinity of the said nozzle but outside the path of flow of the said jet of cryogenic coolant from the said nozzle to the heated weld zone, the vapour space being open to the atmosphere outside the apparatus, and at least one second passage terminating in at least one outlet for ejecting at least one jet of auxiliary gas towards a region of the surface area of the work adjacent to the heated weld zone so as to cause the vapour of the cryogenic coolant to pass into the said vapour space, from where it can be extracted through the first passage, and to limit escape of the vapour of the cryogenic coolant along the surface of the work.
2. Apparatus according to claim 1, in which the first passage has an endless mouth.
3. Apparatus according to claim 1 or claim 2 in which the outlet of the second passage is endless and circumscribes the mouth of the first passage.
4. Apparatus according to any one of the preceding claims in which the said outlet of second passage has a configuration so as in use to provide the auxiliary gas as it exits the said outlet with a radial component of velocity.

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5. Apparatus according to claim 4, in which the outlet of the second passage has a configuration so as in use to direct the jet of auxiliary gas inwards at an angle in the range of 45° to 70° to the surface of flat work being welded.
- 5
6. Apparatus according to any one of the preceding claims in which the nozzle is configured so as in use to direct the jet of cryogenic coolant normally to surface of flat work being welded.
- 10 7. Apparatus according to any one of the preceding claims, in which the nozzle, first passage and second passage are all provided in a single one-piece head.
- 15 8. Apparatus according to claim 1, in which the nozzle and the first passage are provided in a single one-piece head, but the second passage is defined in a separate member.
9. Apparatus according to claim 1 or claim 8, wherein the first passage has an arcuate mouth.
- 20 10. Apparatus according to any one of claims 1, 8 and 9, wherein the apparatus is arranged to move as a unit over the weld.
11. Apparatus according to claim 10, wherein the nozzle has a configuration such that as, in use, the unit is moved over the weld the jet of cryogenic coolant has a rearward component of velocity.
- 25 12. Apparatus according to claim 10 or claim 11, wherein the second outlet has a configuration such that as, in use, the unit is moved over the weld the jet of auxiliary gas has a forward or inward component of velocity.
- 30

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13. Apparatus according to any one of claims 1, and 8 to 12, wherein the outlet of the second passage is of a generally arcuate or horseshoe shape.
- 5 14. A method of forced cooling of a heated weld zone in work being welded, the method comprising directing at least one jet of cryogenic coolant at the heated weld zone, extracting vapour of the cryogenic coolant from a vapour space in the vicinity of but outside the path of flow of the said jet of cryogenic coolant to the heated weld zone, the
10 vapour space being open to the atmosphere, and directing at least one jet of auxiliary gas towards a region of the surface area of the work adjacent to the heated weld zone, the said jet of auxiliary gas causing passage of vapour of the cryogenic coolant into the said vapour space and limiting escape of the vapour of the cryogenic coolant along the
15 surface of the work.
15. A method according to claim 14, wherein the auxiliary gas is air.
16. A method according to claim 14 or claim 15, in which the cryogenic
20 coolant is a jet of solid carbon dioxide, formed by passing a stream of pressurised liquid carbon dioxide through a nozzle.
17. A method according to any one of claim 14 to claim 16, wherein the liquid carbon dioxide is supplied to the nozzle at a pressure in the
25 range of 15 to 25 bar.
18. A method according to any one of claims 14 to 17, wherein the jet of cryogenic coolant is ejected at a supersonic velocity.

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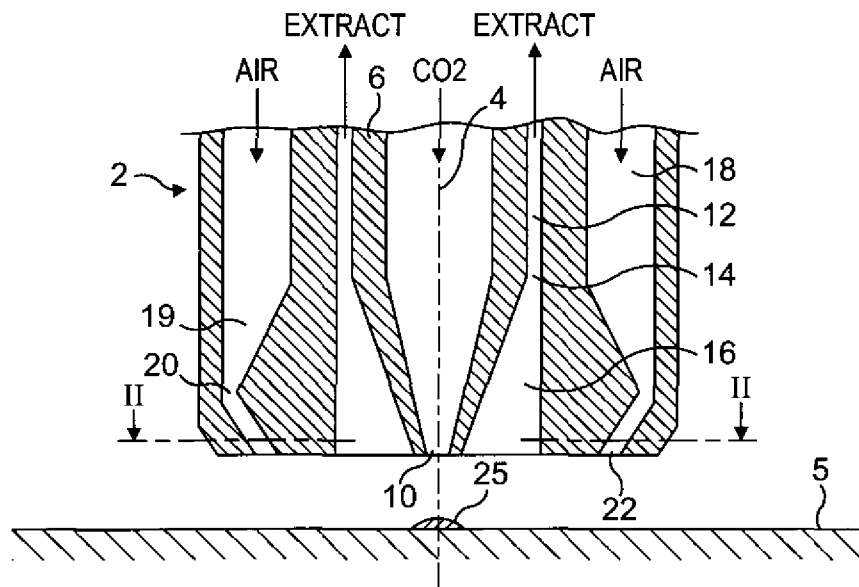


FIG. 1

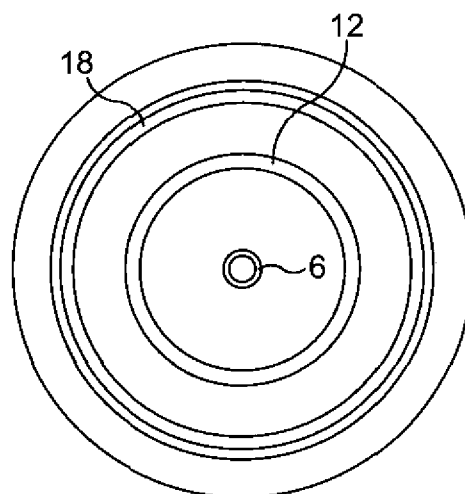


FIG. 2

2 / 3

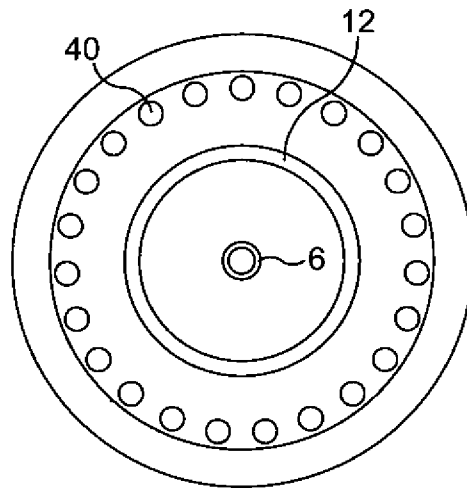


FIG. 3

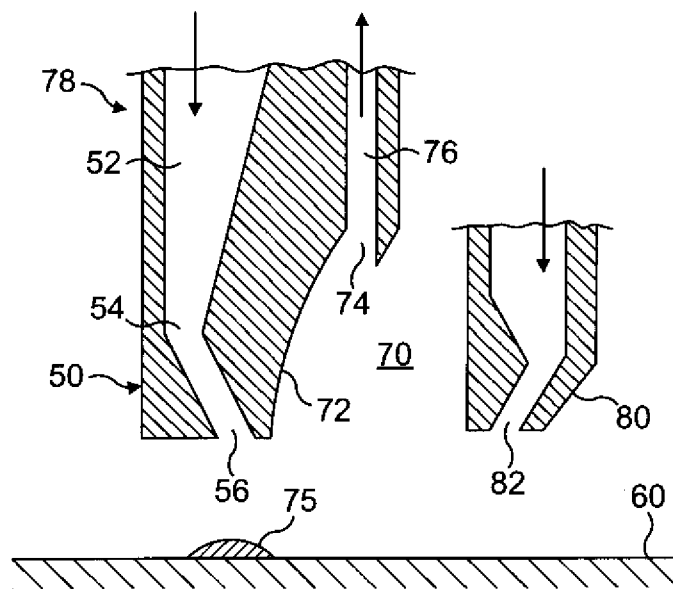


FIG. 4

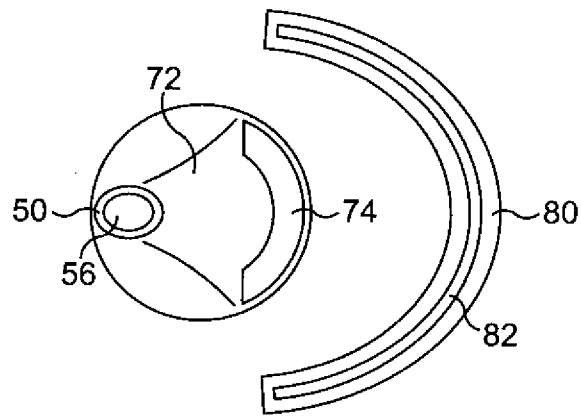


FIG. 5

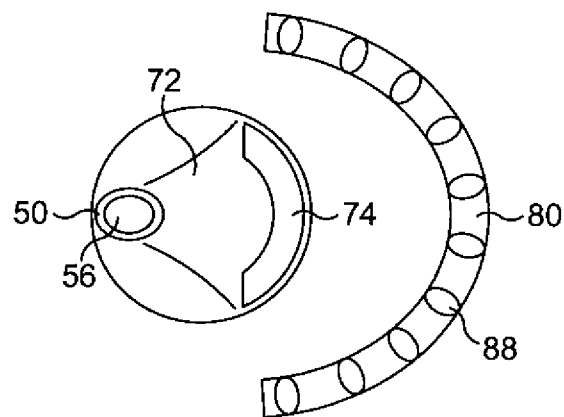


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2007/050339

A. CLASSIFICATION OF SUBJECT MATTER
INV. B23K37/00 C21D9/50

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)
B23K C21D B23Q F23D

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 practical, 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.
A	WO 2005/021204 A (TOYOTA MOTOR CO LTD [JP]; KOZUKA HIROSHI [JP]; SUZUKI MINORU [JP]; NOM) 10 March 2005 (2005-03-10) abstract; figure 1	1, 14
A	EP 1 151 820 A (BOC GROUP PLC [GB]) 7 November 2001 (2001-11-07) claims 1-7; figure 2	1, 14, 16, 17
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT

International application No

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