

LOW-DISTORTION WELDING METHOD AND DEVICE

Technical field

The invention relates to the field of low-distortion welding methods and devices, particularly for assembling metal sheets using fluidtight welds.

5 **Technological background**

FR-A-2701415 discloses an electric arc welding machine for fillet welding two metal sheets of a membrane of a fluid containment tank. However, it has been found that, when attempts are made to reduce the thickness of the sheet metal used, the effects of thermal deformation of the sheets increase and make it more difficult to
10 obtain an assembly of very high quality, notably with regard to mechanical integrity and/or fluidtightness.

Summary

One idea underlying the invention is that of proposing methods and devices that make it possible to reduce the effects of thermal deformation of the sheets during
15 welding. One idea underlying the invention is that of proposing methods and devices suited to use on various walls of a fluid containment tank, whatever the orientation of the wall.

For that, the invention provides a low-distortion welding method involving:

- creating a weld bead for assembling two metallic components, the weld bead being
20 created by moving a welding torch along a path of the weld bead,
- passing a cooling applicator over an exterior surface of the weld bead immediately behind the welding torch so as to cool the weld bead, the cooling applicator being made up of a pad of mineral fibers soaked in a liquid coolant.

Thanks to the use of such a cooling applicator made of mineral fibers, it is
25 possible to retain the liquid coolant during a capillarity effect and thus apply the liquid coolant locally to the desired locations, notably to the weld bead and/or to zones immediately adjacent thereto. The risk of producing build-ups and/or uncontrolled runs of liquid coolant are therefore considerably reduced in comparison with spraying liquid coolant directly onto the components that are to be cooled, thereby reducing
30 the risks of corrosion.

In addition, because the location of the liquid coolant is controlled, the quantity of liquid coolant applied to the desired locations can be controlled more easily and more precisely.

According to one embodiment, the cooling applicator is supplied with liquid
5 coolant as the cooling applicator passes over the weld bead. It is thus possible to obtain continuous and relatively uniform operation of the cooling applicator while the welding is being performed.

The invention also provides a low-distortion welding device comprising a mobile support carriage intended to be moved in an advancing path with respect to
10 two metallic components that are to be assembled, the mobile support carriage bearing:

- a welding torch for producing a weld bead between the two metallic components,
- a cooling applicator arranged behind the welding torch with respect to the advancing path so as to cool the weld bead by contact with an exterior surface of the weld bead,
- 15 the cooling applicator being made up of a pad of mineral fibers, and
- a distribution head designed to distribute a liquid coolant to the cooling applicator so as to soak the pad of mineral fibers with the liquid coolant.

According to some advantageous embodiments, these welding methods and devices may exhibit one or more of the following features.

20 The mineral fibers are chosen for their durability and for their ability to withstand a high temperature, preferably one of at least 1000°C. According to one embodiment, the mineral fibers are made of ceramic. Ceramics, notably refractory ceramics, are heat-resistant materials which also lend themselves well to the formation of fibers.

25 For preference, the mineral fibers are made of ceramic predominantly containing silica in combination with other oxides, notably alumina. Such ceramics offer advantages in terms of chemical inertia, lack of noxiousness, thermal stability and mechanical strength.

The liquid coolant may be chosen from various fluids, notably water and
30 liquid nitrogen. Selection criteria for the liquid coolant are notably its boiling point at standard pressure, its specific heat capacity and its latent heat of vaporization. Water

is a preferred choice given its very high latent heat, its absence of noxiousness, and the ease with which it can be sourced.

The interaction between the cooling applicator and the components that are to be assembled may be designed in various ways in order to achieve effective and controlled contact between the liquid coolant and the weld bead that is to be cooled. In one embodiment, the cooling applicator slides over the exterior surface of the weld bead.

In another embodiment, the cooling applicator is configured to roll over the exterior surface of the weld bead. For that, the cooling applicator may take the form of a cylinder which rolls over the exterior surface of the weld bead, or the cooling applicator may take the form of a "tire" arranged around a cylindrical support to roll over the exterior surface of the weld bead.

Various known technologies can be envisioned for the welding torch. For preference, the welding torch is an electric arc welding torch, for example of Tungsten Inert Gas (TIG) type.

The support carriage can be made to move in various different ways. According to one embodiment, the welding device further comprises a chassis intended to be arranged fixedly with respect to the two metallic components that are to be assembled, the support carriage being mounted mobile on the chassis and guided by the chassis along the advancing path. It is thus possible to obtain precise guidance of the support carriage.

According to one advantageous embodiment, the welding device further comprises a screen borne by the mobile carriage and arranged between the cooling applicator and the welding torch so as to protect the welding torch from splashes of liquid coolant. By virtue of these features, the risk of the welding torch being extinguished or its operation disrupted, particularly in the case of electric arc welding, is reliably avoided.

Advantageously, the cooling applicator is fed with liquid coolant while the cooling applicator is passing over the weld bead.

According to a corresponding embodiment, the welding device further comprises a coolant feed pump connected to the distribution head to feed the distribution head with a flow of the liquid coolant.

The flow of liquid coolant can be regulated in various ways. According to one
5 embodiment, this flow is set to a fixed value. Thus, the welding method may be particularly simple to implement.

According to one embodiment, the welding device further comprises a control unit collaborating with the feed pump and configured to regulate the flow of the liquid coolant according to one or more parameters, for example: a rate of advance of the
10 support carriage, an electric current drawn by the welding torch, etc. By virtue of these features, the flow of the liquid coolant can be controlled automatically and adapted to suit the actual conditions of the welding operation, notably with a view to taking account of the amount of heat that effectively needs to be removed.

According to one embodiment, the welding device further comprises an
15 elastic suspension member for applying pressure to the cooling applicator in the direction of the metallic components that are to be assembled.

This welding method can be used in numerous applications, notably where relatively thin sheet metal is used. One particular application concerns the manufacture of a sealing membrane in a fluid containment tank.

20 In one embodiment, the two metallic components are sheet-metal plates that are to be fillet-welded or butt-welded, the path of the weld bead following the edge of one said sheet-metal plate. Such fillet welding is particularly well suited to the creation of fluidtight welds for the manufacture of a seal membrane in a fluid containment tank.

In one embodiment, the sheet-metal plates are corrugated or checkered.
25 Sheets of checkered plate are notably suitable in applications involving large temperature ranges, and in which the checkering or corrugations of the sheet-metal plates may act as thermal expansion joints. According to one embodiment, the sheet-metal plates comprise a first series of spaced-apart projecting corrugations extending in a first direction of the plane, and possibly a second series of spaced-apart projecting
30 corrugations extending in a second direction of the plane, which direction is perpendicular to the first direction, and flat zones located between the corrugations.

Such a method may be used for welding various metals. Depending on the embodiments, the sheet-metal plates are made from an alloy chosen from unalloyed and weakly alloyed steels, stainless steels, nickel-steel alloys with a low thermal expansion coefficient, and manganese-steel alloys with a low thermal expansion coefficient. In particular, the sheet-metal plates may be made of Invar®, namely an iron and nickel alloy the expansion coefficient of which is typically comprised between $1.2 \times 10^{-6} \text{ K}^{-1}$ and $2 \times 10^{-6} \text{ K}^{-1}$, from a 9% nickel-iron alloy the expansion coefficient of which is typically of the order of $9 \times 10^{-6} \text{ K}^{-1}$ or from an alloy of iron with a high manganese content the expansion coefficient of which is typically of the order of $7 \times 10^{-6} \text{ K}^{-1}$.

Brief description of the figures

The invention will be better understood, and further objects, details, features and advantages thereof will become more clearly apparent, during the course of the following description of a number of particular embodiments of the invention, which are given solely by way of nonlimiting illustration, with reference to the attached drawings.

- **Figure 1** is a schematic side view of a welding device according to a first embodiment.

- **Figure 2** is a perspective view of a welding device according to a second embodiment, used in an application to the fillet-welding of two sheet-metal plates.

- **Figure 3** is a view similar to figure 2 showing the welding device from another angle.

- **Figure 4** is a schematic side view of a welding device according to a third embodiment.

- **Figure 5** is a schematic side view of a welding device according to a fourth embodiment.

- **Figure 6** is a schematic perspective and sectioned view of a cooling applicator that can be used in the welding devices.

- **Figure 7** is a perspective view of another cooling applicator that can be used in the welding devices.

5 - **Figure 8** is an exploded view of the cooling applicator of figure 7.

- **Figure 9** is a photograph taken through an optical microscope of a cross section of a weld bead obtained without using the cooling applicator (large grain size).

10 - **Figure 10** is a photograph taken through an optical microscope of a cross section of a weld bead obtained using the cooling applicator (far smaller grain size).

- **Figure 11** is a schematic perspective view of corrugated metal plates that can be assembled using welding devices.

15 - **Figure 12** is a functional schematic indication of a control system that can be used in the welding devices.

Detailed description of embodiments

Welding devices which comprise a guide rail 1 positioned above the metallic components that are to be welded, and on which a support carriage 2 is mounted with the ability to slide so as to be guided by the guide rail 1 will now be described with reference to figures 1 to 5. The support carriage 2 bears the welding torch 3 facing downward, so that the weld bead produced by moving the support carriage 2 along the guide rail 1 follows a path that corresponds substantially to the path of the guide rail 1. An operation that needs to be performed prior to producing such a weld is therefore that of positioning the metallic components in such a way that the edge that is to be assembled is situated below the path of the guide rail 1 or, which is equivalent, that of placing the guide rail 1 above the location intended for the weld bead. It may in particular be a fixed guide rail, for example attached to the roof of a building, or a mobile chassis that can be positioned detachably on the components that are to be assembled. This second instance is described for example in FR-A-2701415.

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Furthermore, weld beads can be produced on walls exhibiting various orientations, for example in a tank of prismatic shape: a horizontal bottom wall, a vertical or oblique side wall, a horizontal roof wall, etc. In this description, "top" and "bottom" therefore refer to a direction away from the components that are to be assembled and to an opposite direction toward the components that are to be assembled, irrespective of the actual orientation of the components that are to be assembled in relation to the Earth's gravitational field.

In order to operate, the welding torch 3 requires various feeds, depending on the welding technology employed, and these are indicated schematically with numerals 5 and 6 in figure 1, for example supplies of electricity, cooling water, inert gas, combustible gas, etc. These feeds may be achieved using flexible conduits from sources which are independent of the support carriage 2.

The advancing direction 7 of the support carriage 2 is indicated by an arrow. Behind the welding torch 3, the support carriage 2 bears a cooling applicator 8 made of mineral fibers, which may be produced in various ways, in this instance configured like the "tire" of a wheel 9 designed to roll over the weld bead in the advancing direction 7.

The cooling applicator 8 is preferably made up of a fleece of refractory fibers made of ceramic. For example, fleeces available from the Morgan Crucible Company plc, under the trade name Cerablanket™ (128 kg/m³) may be used. This is a ceramic predominantly containing silica of formula SiO₂, a high proportion of alumina of formula Al₂O₃, and other oxides in very small quantities, notably oxides of iron, titanium, calcium, magnesium, sodium and potassium. It is able to withstand a temperature ranging up to 1260°C and has an ultimate tensile strength equal to 90 kPa. Other mineral fibers may also be used.

The wheel 9 comprises a hub 10, for example made of metal or plastic, pivot-mounted about a horizontal axle perpendicular to the advancing direction 7, at the lower end of a support arm 11 secured to the support carriage 2.

The support arm 11 may be coupled to the support carriage 2 in various ways. In figure 1, the upper end of the support arm 11 is pivotingly attached at the top of the body of the welding torch 3, so as to allow the wheel 9 to rise and fall with respect to

the welding torch 3 as the support carriage 2 progresses, in order notably to negotiate reliefs in the component that is to be welded, for example corrugations in a sheet-metal plate. In figure 4, the support arm 11 is made of two parts, articulated in a pivoting manner for the same reason, and the upper part of the support arm 11 is
5 attached directly to the support carriage 2 independently of the welding torch 3.

In figures 2 and 3, the support arm 11 is pivot-connected via an axle 14 to a longitudinal flange 12 secured to a screen 13 attached to the support carriage 2. The screen 13, also indicated schematically in figures 1 and 4, is a solid plate arranged below the support carriage between the welding torch 3 and the wheel 9 and
10 extending perpendicular to the advancing direction 7.

In service, the wheel 9 rolls along the weld bead which has just been formed by the welding torch 3, and applies to it a liquid coolant, for example water, so as to immediately cool the material, this having the effect of reducing the thermal distortion of the assembled components, particularly when these are thin sheet metal. In order
15 to do that, the cooling applicator 8 needs of course to remain sufficiently soaked with the liquid coolant throughout the welding operation.

The feeding of liquid coolant to the cooling applicator 8 could be performed by a device independent of the support carriage 2. However, it is more practical to provide a feed head 15, for example a nozzle, attached to the support carriage 2 and
20 oriented in such a way as to spray the liquid coolant onto the cooling applicator 8 either continuously or intermittently. The feed head 15 is connected by a flexible hose 16 to a feed source, for example a water pump, which may be independent of the support carriage 2.

The feed head 15 may be arranged in various ways. In figure 1, the feed
25 head 15 is above the wheel 9 in order to wet an upper portion of the wheel 9. In figure 4, the feed head 15 is behind the wheel 9 in order to wet a rear portion of the wheel 9. Still other configurations are possible, for example in front of the wheel or to the side. The feed head 15 is not depicted in figures 2 and 3; it could be above the wheel 9 as in figure 1.

30 In the embodiment illustrated in figure 5, the cooling applicator 8 slides over the weld bead behind the welding torch 3 in the advancing direction 7. To do that, the

cooling applicator 8 made of mineral fibers is configured here as a thick parallelepipedal or cylindrical pad housed in a housing 35 in the shape of a rectangular-section or circular-section tube. The feed head 15 is mounted in the housing 35, oriented toward the bottom, in order to deliver liquid coolant onto an upper surface 34 of the cooling applicator 8. The liquid coolant reaches the surface 36 of the welded components by diffusing through the thickness of the cooling applicator 8, which is porous. The housing 35 confines splashes and runs of liquid coolant so that it also protects the welding torch 3 from any splashing, by acting as a screen.

The welding torch 3 and the housing 35 may be mounted independently of one another on the support carriage 2. In the example of figure 5, they are suspended from the support carriage 2 by elastic suspensions 37 and 38 which apply a pressure downward toward the bottom, so as to be able to follow a profile in relief. Fixed or pivoting mounting on the support carriage 2 is also conceivable, depending on the target application.

Figure 6 illustrates the housing 35 in an alternative form of embodiment, viewed in diametral section and in perspective, in which housing grating elements 39 apply pressure to the upper surface 34 of the cooling applicator 8, under the effect of suspension springs 40 mounted to bear between the grating elements 39 and a support bar 41 fixed inside the housing 35. The grating elements 39 allow the cooling applicator 8, which is flexible, to be made to conform to the shape of the component that is to be welded, notably when negotiating a corrugation, without impeding the passage of the liquid coolant.

In one embodiment, the coolant feed source is automatically regulated by a control unit 26 indicated schematically in figure 12. The control unit 26 makes use of input signals supplied by various sensors 27 and representing various operating parameters of the welding station, for example a rate of advance v of the support carriage 2, a flow rate D of liquid coolant, an electric current I drawn by the welding torch 3, etc. Using a control program, the control unit 16 generates control signals for operating a circulation pump 28.

Objectives that may be pursued by such a control program include for example:

- complete or near-complete evaporation of the liquid coolant, in order to avoid build-ups of liquid which may encourage corrosion or prove dangerous in the presence of electrical sources,

- lowering the temperature of the weld bead to below a certain threshold.

5 The control unit 26 may also be used to jointly control various actuators of the welding station, for example a drive motor 29 for driving the support carriage 2, a source of electrical current 30 for the welding torch, etc.

10 Figures 7 and 8 depict a wheel 109 comprising another embodiment of the cooling applicator 108. Here, the cooling applicator 108 is made up of three porous disks made of mineral fibers forming both the hub and the "tire" of the wheel 109. These three disks are clamped between two rigid end plates 20 and engaged on two stub shafts 21 which project toward one another from the center of the two end plates 20. In this embodiment, the volume of liquid that can be absorbed by capillarity is higher. The rest of the operation is identical.

15 The cooling applicator is not necessarily a wheel. In one embodiment which has not been depicted, it is a pad of mineral fibers sliding over the weld bead.

20 As can best be seen in figure 2, in one embodiment, the welding device is used for fillet-welding two flat sheet-metal plates, which means to say welding them with an overlap. More specifically, the welding torch 3 is guided along the edge 17 of the upper sheet 18 which overlaps the lower sheet 19 and produces the weld bead 22 along the edge 17.

25 Figures 9 and 10 show a view in cross section of such a weld bead on two invar® sheets 0.7 mm thick, when the cooling applicator has not been used (fig. 9) and when it has been used (fig. 10). The reference scales E in figures 9 and 10 measure 200 µm.

30 The photographs through an optical microscope make it possible to assess the grain size of the material in the region of the weld bead 22. In figure 9, the melted zone embodied by a coarser grain size extends through the entire thickness of the assembly, right out to the lower surface of the bottom sheet 19. By contrast, in figure 10, the grain size in the weld bead 22 decreases rapidly with depth and a lower half

23 of the lower sheet 19 has more or less maintained its original grain size, demonstrating that the melted zone is more highly localized and less deep. This is the result of the thermal pumping performed by the cooling water.

Such fillet welding can be used to create fluidtight assemblies in a sealed-
5 tank membrane, notably between two corrugated-sheet plates. One example of such a membrane is depicted in figure 11.

Two corrugated-sheet plates 18 and 19 are depicted. The sheet-metal plates 18 and 19 comprise a first series of corrugations 31, projecting on a lower face in the figure and spaced apart at a regular spacing, which extend in a direction y of the
10 plane, and a second series of corrugations 32, likewise projecting on the lower face in the figure and spaced apart with a regular spacing, extending in a direction x perpendicular to the direction y. Flat zones 33 are arranged between the corrugations 31 and 32.

A fillet weld can be produced in the same way along the edge 17 by moving
15 the support carriage 2 with the welding torch 3 in the direction x.

Numerical example

The required cooling water flow rate was measured experimentally by weighing the wet applicator before and after welding, with the following operating
20 parameters: welding energy equal to 89 kJ/m, corresponding to a current $I=43\text{A}$, a voltage $U=11.7\text{ V}$ and a rate of advance $v=34\text{ cm/min}$. A water flow rate of 8.6 ml/m, namely of 0.097 ml/kJ was measured, achieving complete evaporation of the cooling water with no observable buildup.

Theoretical calculations give a water consumption of 8.9 ml/m under the
25 same conditions. The calculations are based on the assumption of a temperature increase from 20°C to 100°C followed by evaporation of the water, causing a metal cooling from 800°C to 500°C. The convergence between these results shows that the liquid coolant is effectively completely consumed by the thermal pumping, rather than dispersed into zones where it is not needed. This corresponds to a minimum flow rate
30 of the order of 8 ml/m for a welding energy of 89 kJ/m, namely approximately 0.090 ml/kJ. If there is a desire to reduce still further the metal temperature obtained

after the passage of the cooling applicator, the flow rate can be increased up to around 20 ml/m without an accumulation of water, namely to around 0.225 ml/kJ. These results are given by way of indication and give an order of magnitude for the amount of water needed to cool a fillet weld between two 0.7 mm thick metal sheets.

- 5 The use of the verb "comprise", "involve" or "include" and the conjugated forms thereof does not exclude the presence of elements or steps other than those listed in a claim.

In the claims, any reference sign between parentheses should not be interpreted as imposing a limit on the claim.

CLAIMS

1. A low-distortion welding method involving:
creating a weld bead (22) for assembling two metallic components (18, 19), the weld
bead being created by moving a welding torch (3) along a path of the weld bead,
5 passing a cooling applicator (8) over an exterior surface of the weld bead immediately
behind the welding torch so as to cool the weld bead, the cooling applicator being
made up of a pad of mineral fibers soaked in a liquid coolant.
2. The method as claimed in claim 1, in which the mineral fibers are
made of ceramic.
- 10 3. The method as claimed in claim 2, in which the mineral fibers are
made of ceramic predominantly containing silica in combination with other oxides.
4. The method as claimed in any one of claims 1 to 3, in which the
cooling applicator (8) is supplied with liquid coolant as the cooling applicator passes
over the weld bead.
- 15 5. The method as claimed in any one of claims 1 to 4, in which the
liquid coolant is chosen from water and liquid nitrogen.
6. The method as claimed in any one of claims 1 to 5, in which the
cooling applicator (8) slides over the exterior surface of the weld bead.
7. The method as claimed in any one of claims 1 to 5, in which the
20 cooling applicator (8) is configured to roll over the exterior surface of the weld bead.
8. The method as claimed in claim 7, in which the cooling applicator
(8) takes the form of a "tire" arranged around a cylindrical support to roll over the
exterior surface of the weld bead.
9. The method as claimed in any one of claims 1 to 8, in which the
25 welding torch (3) is an electric arc welding torch.
10. The method as claimed in any one of claims 1 to 9, in which the two
metallic components (18, 19) are sheet-metal plates that are to be fillet-welded or
butt-welded, the path of the weld bead following the edge (17) of one said sheet-metal
plate.

11. The method as claimed in claim 10, in which the sheet-metal plates (18, 19) are made from an alloy chosen from unalloyed and weakly alloyed steels, stainless steels, nickel-steel alloys with a low thermal expansion coefficient, and manganese-steel alloys with a low thermal expansion coefficient.

5 12. A low-distortion welding device comprising:
a mobile support carriage (2) intended to be moved in an advancing path with respect to two metallic components (18, 19) that are to be assembled, the mobile support carriage (2) bearing:

a welding torch (3) for producing a weld bead (22) between the two metallic
10 components,

a cooling applicator (8) arranged behind the welding torch with respect to the advancing path so as to cool the weld bead by contact with an exterior surface of the weld bead, the cooling applicator being made up of a pad of mineral fibers, and a distribution head (15) designed to distribute a liquid coolant to the cooling applicator
15 (8) so as to soak the pad of mineral fibers with the liquid coolant.

13. The device as claimed in claim 12, further comprising a chassis (1) intended to be arranged fixedly with respect to the two metallic components that are to be assembled, the support carriage (2) being mounted mobile on the chassis and guided by the chassis (1) along the advancing path.

20 14. The device as claimed in claim 12 or 13, further comprising a screen (13, 35) borne by the mobile carriage and arranged between the cooling applicator (8) and the welding torch (3) so as to protect the welding torch from splashes of liquid coolant.

25 15. The device as claimed in any one of claims 12 to 14, further comprising:

a coolant feed pump (28) connected to the distribution head (15) to feed the distribution head with a flow of the liquid coolant, and

a control unit (26) collaborating with the feed pump and configured to regulate the flow of the liquid coolant according to one or more parameters chosen from the group
30 consisting of: a rate of advance of the support carriage (2), an electric current drawn by the welding torch (3).

16. The device as claimed in any one of claims 12 to 15, further comprising an elastic suspension member (38, 40) for applying pressure to the cooling applicator (8) in the direction of the metallic components (18, 19, 36) that are to be assembled.