

Title: A Welding Process

THIS INVENTION relates to a welding process and more particularly to a welding process adapted to provide an overlay of hard metal applied onto the surface of base metal, the hard metal exhibiting good wear resistant properties.

A large number of wear resistant materials have been heretofore used in various kinds of machine and equipment in many industrial fields. Techniques employing such metals are commonly employed in connection with almost all components and parts such as rollers, roller tyres, table segments, hoppers, shoot liners, etc. which are mounted on vertical mills respectively used, for example, in the crushing of coal used in boilers for thermal power generation, and in the crushing of cement clinker or blast furnace slag, the surfaces of which are exposed to strong abrasion or wear due to contact with coarse raw materials. The wear resistance is not always required over the whole of each member, but it is sufficient for only that part of the surface contacting the raw materials to have such wear resistance. In this situation, the wear resistance can be achieved just by applying a hard metal to the required wear resistant surface using a welding process. It is also possible to perform a welding process of this type on a worn surface to recondition the surface when part of the surface has worn due to operation of the mill.

Generally, the area of a contact surface required to have wear resistance is rather large. Therefore, whether it is a welding process carried out during initial manufacture or a subsequent rebuilding, effective welding is required. As a result, so-called fully automatic

welding processes such as CO₂ welding, MIG welding, submerged arc welding, etc. have been employed for the purpose of forming a wear resistant surface.

In forming a wear resistant surface by the above-described overlaying process, it is a matter of course that deposited metal of higher hardness can achieve higher wear resistance. As is well known, however, a serious problem exists in that the deposited metal of higher hardness has less toughness, which brings about the disadvantage of lack of resistance to the shrinkage stress that can occur with a welding process, eventually resulting in easy occurrence of underbead cracking. This disadvantage is particularly conspicuous in base metals which are generally considered not suitable for welding.

The possibility of spalling of the overlaying layer due to the occurrence of underbead cracking increases when the hardness of the deposited metal is high. Accordingly, in the prior art, the hardness of the overlaying layer has necessarily been restricted to being no higher than 600 Hv, in spite of the insufficient wear resistance thereof. Also, the thickness of the entire overlaid layer is necessarily restricted to being 2 to 3 layers (6 to 10 mm), which gives rise to another problem in that the wear resistant portion can only have a rather small thickness.

In order to overcome the above-mentioned problems, several approaches have been proposed heretofore. For example, to prevent spalling, preheating at 250 to 600°C is introduced before the overlaying work, and in order to ensure sufficient toughness a high temperature is maintained during the overlaying work. A further approach is to perform an annealing step to eliminate welding stress by introducing the overlaid portion, immediately after

welding, into a furnace at 600 to 700°C. In practice, however, such preheating at high temperature and welding under high temperature is very difficult. Even if one succeeds in eliminating welding stress by annealing at high temperature, there still remains a further problem, namely of a reduction in hardness of the overlaid layer, due to the temperature experienced during the annealing step.

Further attempts to solve the cracking problem have been proposed, in which a welding process with a material enabling high hardness to be obtained and welding with a material of superior toughness are alternately repeated like a sandwich (Japanese Laid-Open Patent Publication No. 56-71578), or in which welding conditions are varied periodically so as to alternate between a large and a small welding bead width, thereby positively generating weld cracks at the portions where the welding bead width is small (Japanese Laid-Open Patent Publication No. 60-21070). A further approach has been proposed, wherein a number of grooves are formed and a number of hard-facings are applied transversely to these grooves so as to generate, intentionally, bead cracks at the portion where the bead extends across the groove (Japanese Laid-Open Patent Publication No. 60-174266).

Whilst any of the foregoing prior art procedures can provide a partial solution to the problems, there still remain disadvantages to be overcome. In the first prior art document mentioned above (Japanese Laid-Open Patent Publication No. 56-71578), because of alternate accumulative deposits of a layer having superior wear resistance and another less resistant layer, it is needless to say that this construction is inferior in wear resistance as compared with an arrangement entirely comprised of wear resistant layers. Likewise in the second

prior art document mentioned above (Japanese Laid-Open Patent Publication No. 60-21070), this process may be theoretically appreciated, but in reality a practical problem exists in selecting the pitch length of adjacent regions of the bead of greater width and of lesser width. It is difficult to distribute small cracks by shortening a distance between one crack (a portion of small bead width) and another (next portion of small bead width). For example, even if it is ideal to disperse cracks at 5 mm intervals, actual achievement of this ideal will be difficult because the cracks are excessively large. Also there is a probability that the remaining welding stress in the bead of such an arrangement eventually results in insufficient protection of the bead from partial spalling.

In the case of last prior art document discussed above (Japanese Laid-Open Patent Publication No. 60-174266), it is essential to provide a large number of fine recess grooves on a surface such as a liner of large area. Not only is this requirement troublesome but also it will be almost impossible to repeat the same process as the initial one to carry out reconditioning after use of the apparatus to recover wear resistance.

According to this invention there is provided a welding process with hard metal comprising the steps of applying at least one layer of welding of hard metal onto a surface of base metal, which limits the heat input value J , to be in the range of 2000 to 6000 J/cm; said heat input value J being calculated by:

$$J = 60 \times I \times E/v$$

where: J is heat input value (J/cm); E is arc voltage (V); I is welding current (A); v is welding speed (cm/min) and limiting the interpass temperature to be not higher than 300°C at all times so that a large number of fine cracks

are evenly and dispersedly produced on a bead of deposited metal in a direction perpendicular to the axis of the bead.

Preferably a plurality of layers of welding are superimposed.

It is preferable that an open arc fully automatic welder is employed, that a flux cored wire is employed to be used in this welder, and that a high speed wire feeding device capable of feeding more than 600 cm/min and up to 3000 cm/min is employed in the welding process.

With regard to the hard metal used in the overlaying process, it is preferable that its hardness is over 600Hv. Not only is the number of over-laying layers not limited but also the thickness thereof is permitted to be freely established. To satisfy these requirements, a satisfactory hard metal is a steel alloy composed of C: 3.0 to 7.0%, Si: 0.5 to 2.0%, Mn: 0.5 to 4.0%, Cr: 20.0 to 35.0%; and at least one component selected among Mo, W, V, Zr, Ti, B, Nb, Cd, Co, Al which is added to 2%. An alternative hard metal is a steel alloy composed of C: 3.0 to 7.0%, Si: 0.5 to 2.0%, Mn: 0.5 to 4.0%, V: 10.0 to 20.0%, W: 3.0 to 10.0%; and at least one component selected among Mo, Zr, Ti, B, Nb, Cd, Co, Al which is added in the ratio of up to 2%.

In performing the process of the above arrangement according to the invention, it has been found that fine cracks are dispersed or distributed evenly and in large number in the direction perpendicular to welding stress on a deposit, whereby stress around the cracks is reduced to the extent that residual welding stress on the entire bead is substantially ignorable.

The welding stress has been heretofore one of the serious problems, because the deposited welding portion generates shrinkage stress as a result of cooling and solidification and there is a remarkable difference in material properties (such as strength, hardness, toughness) between said deposit and base metal in hard-facing, hence stress is concentrated at the boundary between said deposit and said base metal and this produces large cracks eventually resulting in spalling. To solve the problem, several attempts have been proposed as mentioned above in order to achieve an intentionally even dispersion of the cracks. The present invention has accomplished this desired function by a novel concept of limiting the interpass temperature to be not higher than 300°C and limiting the heat input J to be in the range of 2000 to 6000 J/cm.

It has been generally understood that a higher interpass temperature during the welding process is more desirable, as this provides poor toughness to prevent occurrence of large cracks. For this reason, the fact is that rather difficult steps have been forced to be taken, such as performing preheating at high temperature and keeping the welding temperature high during the welding process.

The invention differs from this conventional conception. Moreover, with respect to the heat input J, the following formula is a known principle:

$$J = 60 \times I \times E/v$$

where: J is heat input value (J/cm); E is arc voltage (V); I is welding current (A); v is welding speed (cm/min)

It is certain that the heat input calculated by the above formula varies depending upon the manner of

welding as shown in Table 1, which shows data for various prior proposed welding processes, but any of the values shown in this table are largely different from the required value (2000 to 6000 J/cm) of the invention.

TABLE 1

Welding Process (ϕ = mm/dia)		Welding Conditions			Heat Input (J/cm)
		Current (A)	Voltage (V)	Speed (cm/min)	
Covered electrode 4.0 ϕ		170	27	15	18,000
Semi- auto weld	Solid wire 1.5 ϕ	400	25	40	15,000
	Flux cored wire 3.2 ϕ	400	26	40	16,000
Submerged arc welding		500	30	30	30,000
Surfacing with strip electrode		800	25	18	67,000

The heat input according to the invention has a lower limit of 2000 J/cm because it becomes effectively impossible to carry out overlaying if the heat input is less than this, due to the poor melting rate of the metal melted by the arc. On the other hand, if heat input is over 6000 J/cm, the thickness per bead given by overlaying becomes excessively large, thereby enlarging a gap between one crack and another. Consequently, a large and deep crack is produced at each location, which brings about an increase in the residual stress in the bead between cracks. Such cracks propagate easily, eventually resulting in

spalling. To avoid such a disadvantage, the mentioned value is established in the invention as the upper heat input limit.

If the interpass temperature is over 300°C , the solidification speed of the deposited metal is reduced thereby enlarging the dimension of the crack on the welding bead whilst decreasing the number of cracks. This results in an increase in the residual stress between one crack and the other. To avoid this disadvantage, 300°C is established as the upper temperature limit.

An open arc fully automatic welder may be selected as the welding machine. This selection is made mainly because of simplicity in welding work, i.e. no addition of sealed gas, flux or the like is needed. Consequently, the equipment is relatively simple and the assembling of the entire equipment including auxiliary jigs (such as manipulator, positioner, etc.) is relatively easy and furthermore it is also easy to carry the equipment. This is a great advantage when it is necessary to go to a remote working site (which is difficult to access) where rebuilding with wear resistant material is to be performed for reconditioning.

It is preferable to employ flux cored wire as a cored wire for use in the open arc fully automatic welder. This flux cored wire is composed of a thin strip of steel plate formed into a pipe, into the hollow part of which a mixture of fine particles of alloy components, deoxidizer, gas generating components is inserted to form a wire. The outer peripheral steel plate portion of this cored wire has a property of being able to carry a very large current density as compared with a solid wire, and of which the melting speed is very high.

Further, to utilise the aforementioned property, it is preferable to employ a four wheel drive high speed wire feeder in the welding machine, capable of feeding up to 3000 cm/min in place of the conventional speed of up to 600 cm/min.

As a result of selecting the mentioned flux cored wire, the alloy elements to be used in the hard-facing can be selected from a wide range, and it is possible to select any component and/or the hardness most suitable for the individual wear conditions. It is to be noted that in the prior art, hard-facing has been possible, at maximum, only up to Hv600 in hardness, and only with a maximum of 2 to 3 layers of which the height is 6 to 10 mm. On the other hand, in the present invention, when performing the same process using the aforementioned welding machine to satisfy the same welding requirements as mentioned, a high hard overlaying of Hv600 to 1000 can be formed at any desired thickness.

As representative components for the overlay according to the invention, the following materials can be adopted: (1) materials of high Cr carbide such as C:3.0 to 7.0%, Mn:0.5 to 4.0%, Cr:20.0 to 35.0%; and (2) materials of high V carbide such as C:3.0 to 7.0%, Mn:0.5 to 4.0%, V:10.0 to 20.0%, W:3.0 to 10.0%. It may be further preferable to add one or more elements among Mo, W, V, Zr, Ti, B, Nb, Cd, Co, Al to the mentioned two materials up to 2.0% depending upon wear conditions.

It is generally recognized that welding material for use in hard-facing is prepared employing alloy elements which are easily carbonized, and every carbide composed of such elements has a high hardness. The deposit hardness obtained by overlaying is almost in proportion to the total

amount of these carbides. Furthermore, since the hardness of deposits, including these alloy elements, is generally almost in proportion to the amount of carbon added, it may be said that a large amount of carbon (e.g. a carbon content of C:3.0 to 7.0%) performs a principal function for forming an overlaid layer of high hardness.

The welding consumables of high carbon and high alloys herein are highly susceptible to cracking. Their frequency of cracking occurrence is high in proportion to solidification speed. In prior art processes the number of occurrences of cracks is decreased with the process of annealing, and thus occurrence of large cracks is reduced.

In the invention, as a result of restricting the heat input J during welding to be extremely low, and performing the welding process at high speed at a low interpass temperature, the solidification speed of the deposit becomes very high. Consequently a large number of cracks are formed which are evenly distributed so as to release most of the residual stress existing in the entire built-up layer and preventing the generation of large cracks which may result in partial spalling.

In the multi-layer overlaying process with hard metal according to the invention, it is possible to achieve an overlaying layer of higher hardness and larger thickness than the prior art. Accordingly, wear resistance and life time of the overlaid portion are remarkably improved. Further, since the welding speed is very high, welding efficiency is also improved. Moreover, the construction of the welding machine itself is simple, so that the welding machine may be portable, thereby enabling rebuilding work to be carried out at a remote site.

In addition, the welding process of the invention is performed by providing layers of a deposited metal of high hardness, one by one, thereby forming a plurality of layers. The technique of the invention is applicable not only to a base metal of soft metal of good weldability but also, for example, to a high carbon cast material (such as Ni-Hard cast iron) with rebuilding easily performed.

In order that the invention may be more readily understood, the invention will now be described by way of example with reference to the accompanying drawings in which:

FIGURE 1 is a front view showing the positions at which a microphotograph of metal structure in an embodiment according to the present invention was taken;

FIGURE 2 is a microphotograph showing the metal structure taken along the line A-A in Figure 1;

FIGURE 3 is a microphotograph showing the metal structure taken along the line B-B in Figure 1; and

FIGURE 4 is a macrophotograph showing a metal structure of another embodiment.

In one example of the present invention, a cylinder of 900 mm in diameter made of high Cr carbide wear-resistant casting is overlaid with a high Cr carbide flux cored wire of 3.2 mm in diameter, of which the base is Fe and containing C:6.0%, Cr:27% and other components, by means of an open arc automatic welder under the following conditions:

Welding Conditions

(1)	Welding current	400 Amp
(2)	Welding voltage	28 V
(3)	Travelling speed	180 cm/min

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|-----|---------------------------------------|-----------|
| (4) | Interpass temperature | 300°C max |
| (5) | Heat input | 3700 J/cm |
| (6) | Sealed gas, preheating, afterheating: | None |

The high Cr carbide wear resistant casting (C:2.7%, Cr:27%) employed as a base metal in the aforementioned Example 1 was established as Comparative Example 1, and a test material having a hardness of Hv600 to which hard-facing was applied by coating arc welding process according to one of the prior art was established as Comparative Example 2.

Then, the foregoing Example 1, Comparative Examples 1 and 2 were subject to rubber wheel abrasion test (RWAT) under the same test conditions. Table 2 shows the test conditions and Table 3 shows test results.

TABLE 2

(a)	Load on test piece	8.8 Kg
(b)	Revolutions of rubber wheel	6000
(c)	Revolution speed	120 rpm
(d)	Abrasive	Silica sand No. 6
(e)	Abrasive feed amount	300 g/min
(f)	Dimensions of test piece	20x20x50 (mm)

TABLE 3

	Abrasion amount	Abrasion resistance multiple (Comparative example 2: 1.00)
Example 1	102.9 g	2.44
Comparative Example 1	267.4 g	0.94
Comparative Example 2	251.5 g	1.00

It is understood from the Table 3 that Example 1 according to the invention has an abrasion resistance twice as much as the hardfacing according to the prior arts.

Figure 1 shows a position to show microscopic and macroscopic photographs of the structure of Example 1.

Figure 2 is a microscopic photograph taken along the line A-A in Figure 1 and from which it is seen that carbides-like needles are growing toward one direction. Figure 3 is a microscopic photograph taken along the line B-B in Figure 1 and from which it is seen that carbide-like needles are densely growing. Figure 4 is a macroscopic photograph of a metal structure of another example in which a vertical roller was overlaid with a thickness of 30 mm and put into use, and from which it is seen that fine cracks are evenly distributed on the surface with a distance of about 5 mm.

The preferred embodiment of the invention prevents an overlaying portion from partial spalling due to underbead cracking when providing a wear resistant surface with hard metal.

The preferred process of the invention enables plural layers of hard metal, of which the hardness is higher than 600 Hv, to be formed. The layers may have an optional thickness, and there may be any number of overlays, in contrast with the conventional number of overlays, which is usually limited to two or three layers.

In carrying out the preferred process of the invention it is not necessary to perform steps such as: preheating at high temperature before performing the overlaying, keeping a high interpass temperature during the overlaying process, and release of residual welding stress after the overlaying.

The preferred process of the invention is capable of being performed by a known welding apparatus to which only a partial improvement is applied, without any specific work, additional device, particular technique or complicated welding control means being necessary.

CLAIMS:

1. A welding process with hard metal comprising the steps of applying at least one layer of welding of hard metal onto a surface of base metal, which limits the heat input value J , to be in the range of 2000 to 6000 J/cm; said heat input value J being calculated by:

$$J = 60 \times I \times E/v$$

where: J is heat input value (J/cm); E is arc voltage (V); I is welding current (A); v is welding speed (cm/min) and limiting the interpass temperature to be not higher than 300°C at all times so that a large number of fine cracks are evenly and dispersedly produced on a bead of deposited metal in a direction perpendicular to the axis of the bead.

2. A welding process according to Claim 1 wherein a plurality of layers of welding are superimposed.

3. A welding process with hard metal according to Claim 1 or 2, wherein an open arc fully automatic welding process is employed.

4. A welding process with hard metal according to Claim 2 or 3, wherein flux cored wire is employed.

5. A welding process with hard metal according to Claim 3 or 4, wherein a high speed wire feeding device capable of feeding more than 600 cm/min and up to 3000 cm/min is employed.

6. A welding process with hard metal according to any one of the preceding Claims, wherein the hardness of the overlaying hard metal used herein is over 600 Hv.

7. A welding process with hard metal according to any one of the preceding Claims, wherein the overlaying hard metal is composed of (1) C: 3.0 to 7.0%, Si: 0.5 to 2.0%, Mn: 0.5 to 4.0%, Cr: 20.0 to 35.0%; or (2) at least one component selected among Mo, W, V, Zr, Ti, B, Nb, Cd, Co, Al which is added in the ratio up to 2%.

8. A welding process with hard metal according to any one of Claims 1 to 6, wherein the overlaying hard metal is composed of (1) C: 3.0 to 7.0%, Si: 0.5 to 2.0%, Mn: 0.5 to 4.0%, V: 10.0 to 20.0%, W: 3.0 to 10.0%; or (2) at least one component selected among Mo, Zr, Ti, B, Nb, Cd, Co, Al which is added in the ratio up to 2%.

9. A welding process substantially as herein described with reference to the accompanying drawings.
