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Friction welding of dissimilar metal joints with intermediate layers

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Properties

ABSTRACT

Purpose: Metals such as titanium, vanadium, zirconium, niobium, molybdenum and also tantalum and tungsten must be protected at elevated temperatures from the effects of oxygen, nitrogen and hydrogen. For this reason, it is of interest, both from the innovative and practical points of view, to investigate the possibility of using the process of friction welding to produce joints in these materials.
Design/methodology/approach: Investigations were made on the pseudoalloy of tungsten of D18 type an alloy produced by a powder-metallurgy method of sintering tungsten grains, which form the matrix (95% by weight), with the bonding phase formed by Ni-Fe alloy.
Findings: In the course of the direct friction welding of dissimilar metal joints in niobium and titanium with steel and D18 pseudoalloy of tungsten, hard intermetallic phases are formed which cannot be removed from the whole area of the joint. The use of interlayers of metals, which in the solid state do not form intermetallic phases with the metals of the joint, ensures the absence of microcracking in the joint. For the steel-niobium, or D18 pseudoalloy of tungsten-niobium joints, an interlayer of copper can be used, but for joints with titanium an additional vanadium layer is required.
Research limitations/implications: In the case of a joint made in niobium and D18 pseudoalloy of tungsten there is a possibility of intermetallic phases being formed between Nb and bonding elements – Fe and Ti. A very hard zone id formed with many microcracks so further investigations are needed.
Originality/value: The possibility of using the process of friction welding to produce joints in these materials.
Keywords: Metallic alloys; Friction welding

1. Introduction

Friction welding is a joining process that allows more materials and material combinations to be joined than with any other welding process. Besides common material combinations such as steel/steel, friction welding also permits high-quality joining of process-critical materials such as magnesium alloys, aluminum, and steels with a very high carbon content or austenitic structure.

Moreover, a whole range of different material combinations, such as steel/copper, steel/aluminum or aluminum/magnesium, can also be joined without difficulty. The Metals of groups IV, V and VI of the periodic table, especially titanium, vanadium, zirconium, niobium, molybdenum and also tantalum and tungsten can be joined by friction welding – it was discussed in these article. With friction welding, joints are possible not only between two solid materials or two hollow parts: solid material/hollow part combinations can also be reliably welded. Friction-welded parts are characterized by great accuracy in their length and eccentricity. The process is distinguished by very short welding times and thus extremely short cycle times.

Whereas the friction welding of mono-and multimetallic combinations exhibiting either perfect or limited solubility in the solid state does not present any metallurgical problems, the friction welding of materials which interact among themselves, forming intermetallic phases, is often problematical. Nevertheless an attempt has been made to apply this technology to the welding of multimetallic joints in niobium and titanium. As examples of this technique, the following material combinations were chosen: niobium and D18 pseudoalloy of tungsten, titanium and D18 pseudoalloy of tungsten, and steel with titanium.

To protect the joint area from the effect of the atmospheric gases, friction welding was carried out in a liquid [1].

The typical friction welding machine was shown on fig. 1.

Fig. 1. Friction welding machine

2. Friction welding of multimetallic joints in metals forming intermetallic phases

2.1. Niobium - D18 pseudoalloy of tungsten

The pseudoalloy of tungsten of D18 type is an alloy produced by a powder-metallurgy method of sintering tungsten grains, which form the matrix (95% by weight), with the bonding phase formed by Ni-Fe alloy (3.4% Ni and 1.6% Fe both by weight).

This type of material is often used instead of pure tungsten because of comparative case of production and machining.

Bonding of niobium to tungsten doesn't present any difficulties (no intermetallic phases are present in a binary systems). However, in the case of a joint made in niobium and D18 pseudoalloy of tungsten there is a possibility of intermetallic phases being formed between niobium and the constituents of the bonding material (Fe and Ni). that is the forming of phases of Nb-Fe-Ni-W type, hi spite of employing very short welding periods when making the joints, a very hard zone (about 2000 $HV_{0.015}$) 5 - 40 µm wide and with many microcracks was present in all the investigated cases (Fig. 2).

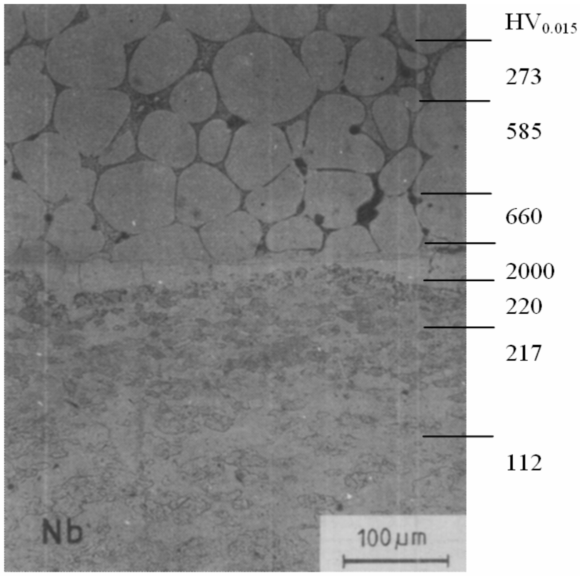

Fig. 2. Microstructure and microhardness of Ni – D18 pseudoalloy of tungsten joint

It was found that in the course of the process of friction welding, partial expulsion of the bonding material out of the pseudoalloy would occur. Thus, nickel and iron, from the bonding phase, react with niobium and tungsten forming, on the joint boundary, a liquid zone. The lowest temperatures a, which the formation of the liquid is possible are 1425 ºC for the Fe-Ni system, but lower at 1373 ºC for the Fe-Nb system, and 1175 ºC for the Nb-Ni system. Consequently, the temperature reached in the course of friction welding is sufficient to produce partial melting of the bonding phase in the pseudoalloy of tungsten. In the layers of niobium, close to the joint area, an increase in hardness to about 220 $HV_{0.015}$ takes place, as compared with the microhardness of the parent metal of 112 $HV_{0.015}$

A linear analysis of the distribution of the elements tungsten, niobium, nickel and iron showed that there occurs diffusion of niobium, exceeding 10% by weight, into the bonding phase of D18 pseudoalloy of tungsten. A local analysis of the hard zone in the niobium-Dl8 weld showed the presence, by weight, of 60-40% of niobium. 10-20% of tungsten. 40% nickel, and about 8% of iron. On the joint boundary, within the hard zone, a peak of carbon, amounting to some 2% (by weight) was present.

It should be mentioned, at this point, that the process of friction welding of niobium to Dl8 pseudoalloy of tungsten takes a different course from that of welding tungsten to niobium. At similar pressures exerted during the frictional phase, in the process of welding niobium to pseudoalloy of tungsten it is only after 30 sec that a contraction of some 0.2mm is produced, whereas in the case of the niobium-tungsten welding a contraction of 13.8 mm occurs after 7.2 sec.

2.2. Titanium - D18 pseudoalloy of tungsten

Friction welding of tungsten-titanium joints docs not present any great problems either [3]. But somewhat different is the problem of welding D18 pseudoalloy of tungsten to titanium. During the production of such joints, the heat affected zone is formed on the side of titanium, being wider in the centre of the specimen, unlike the case of friction welding of titanium to tungsten. The reason for this shape of heat affected zone is a lower quantity of heal evolved when welding D18 to titanium, in comparison with that generated during the welding of tungsten to titanium. To obtain defect-free joints, it was necessary to reduce the rate of rotation from the standard 1500 to 750 min^{-1} . Similarly to the case of Dl8-niobium joints, the contraction of the specimen was very small (l.8mm), while for the tungsten-titanium joints, with a similar set of parameters, it exceeded 30mm.

During welding, a continuous zone of intermetallic phases is formed on the surface of the joint and reaches some 3 µm width, but then it widens on the D18 pseudoalloy of tungsten side where, between the grains of tungsten, it penetrates to a depth of 60 µm (fig.3*)*. Its microhardness is 660 $HV_{0.015}$. The joint obtained is very brittle and is destroyed when the specimen is dropped from a height of 1m on to a concrete base. The X-ray examinations of the titanium-Dl8 fractures showed mainly the presence of inclusions of tungsten, of a solid solution of titanium in tungsten, of titanium and of a few small and difficult to identify inclusions whose frequency was higher for the specimens with wider zones of the intermetallic phase.

The linear analysis of the distribution of tungsten, titanium and iron in the area of the titanium-Dl8 pseudoalloy of tungsten joint shows that on the interface a Ti-Ni-W-Fe phase is produced. A local analysis of the hard phase on the interface showed the following composition of the material: 64% Ti. 26% Ni. 5% W and 5% Fe (all by weight).

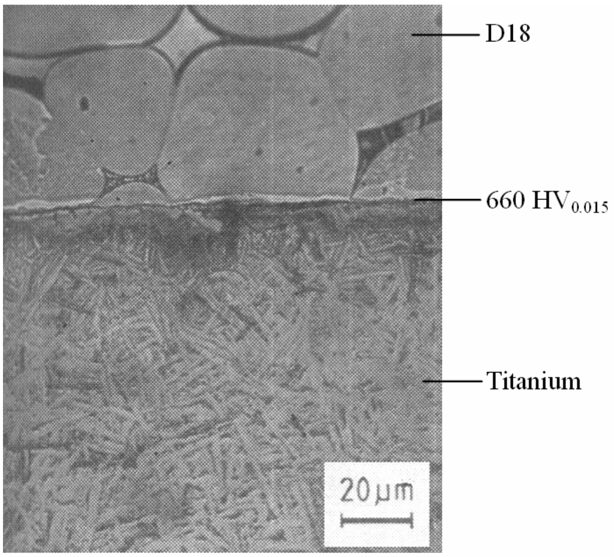

Fig. 3. Microstructure of titanium – D18 pseudoalloy of tungsten joint

2.3. Titanium-iron

The problems associated with the diffusion welding of titanium to steel or titanium to Armco iron have often been investigated [4]. Common features of those investigations were attempts at establishing techniques, on occasions most complicated, which would prevent the formation of intermetallic phases. In practice, however, joints between titanium and steel are not produced by means of those techniques.

The author's own experimentation with the direct welding of titanium to Armco iron showed that it is impossible to prevent intermetallic phases from forming across the whole of the joint. The quantity of heat generated at various points of the surfaces rubbing against each other, a complex function of the distance from the axis of rotation, is instrumental in forming zones containing intermetallic phases. This is particularly so at a distance of about 2/3 of the radius from the centre of the specimen. The use, however, of lower values of welding parameters does not guarantee that a joint will be produced in the whole of the cross-sectional area of the specimen.

Figure 4a shows the microstructure of a titanium-Armco iron joint. In the zone in which the intermetallic phases are present, the microhardness reaches the value of 700 $HV_{0.015}$, and microcracks occur.

The linear element distributions of titanium and iron (Fig. 4b), taken across the joint, show the presence of the phases of the Fe-Ti system.

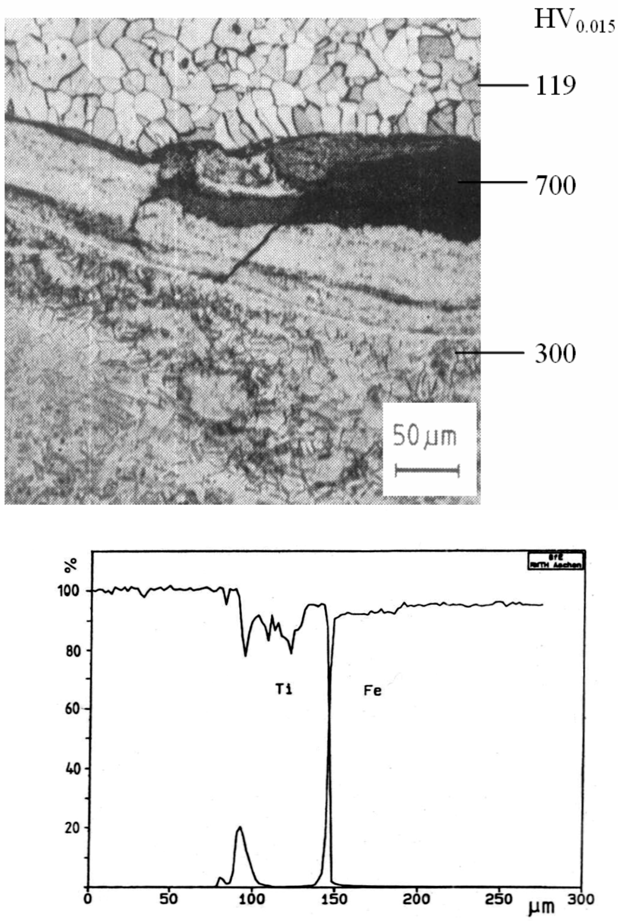

Fig. 4. Titanium – Armco iron joint a) microstructure and microhardness, b) linear distribution of iron and titanium

3. Example of using intermediate layers of copper in niobium and D18 pseudoalloy of tungsten joints

In view of the unsuccessful attempts to produce joints in D18 pseudoalloy of tungsten with niobium, it was decided, on the basis of analyses of binary systems, to use an intermediate copper layer (Fig. 5). Copper does not form intermetallic phases with the bonding phase (Ni and Fe), and does not show any tendency to solubility in tungsten. There are no intermetallic phases in the copper-niobium system, and at temperatures below 1080 ºC a mixture of an α and β solid solution exists. The solubility of niobium in copper at 1080 ºC is 0.1% (at), and that of copper in niobium is 1.2% (at) [2].

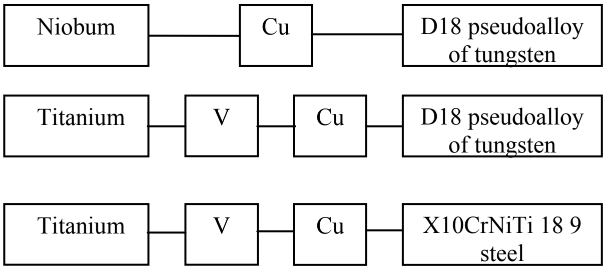

Fig. 5. Interlayer systems in niobum and titanium joints

With copper as an intermediate layer, it is important to use an oxygen-free metal because the quantity of heat evolved during the making of the second joint may prove sufficient to generate microcracking in the area of the first joint on the copper side [5]. For this reason, for the D18-niobium joints, a phosphorus deoxidized copper was used in the form of 35 x 35 x 15 mm platelets. On completing the welding of a D18 pseudoalloy of tungsten -copper joint, the flash would be removed by turning, and the surface of the copper would be levelled to give a layer some 8mm thick. The next joint in niobium-copper-Dl8 combination would then be made. The microstructure of a joint, produced in this manner, in D18 pseudoalloy of tungsten and niobium with a copper interlayer of final thickness of 1.7mm is shown in Fig. 6.

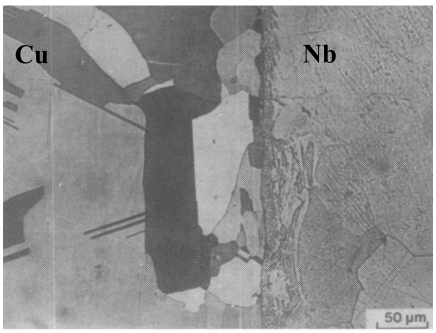

Fig. 6. Microstructure of niobium – D18 pseudoalloy of tungsten joint with copper interlayer

The friction welding of mono-and multimetallic combinations exhibiting either perfect or limited solubility in the solid state does not present any metallurgical problems but the friction welding of materials which interact among themselves, forming intermetallic phases, is often problematical. Nevertheless an attempt has been made to apply this technology to the welding of multimetallic joints in niobium and titanium. This welding technique can be use to join many others combination of materials. For example: to join niobium and austenitic steel, titanium - D18 pseudoalloy of tungsten and vanadium and titanium [6, 7].

4. Conclusions

- In the course of the direct friction welding of dissimilar metal joints in niobium and titanium with steel and D18 pseudoalloy of tungsten, hard intermetallic phases are formed which cannot be removed from the whole area of the joint.
- The use of interlayers of metals, which in the solid state do not form intermetallic phases with the metals of the joint, ensures the absence of microcracking in the joint.
- For the steel-niobium, or D18 pseudoalloy of tungsten-niobium joints, an interlayer of copper can be used, but for joints with titanium an additional vanadium layer is required.

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