Fusion Welding of a Tungsten Alloy to a Tantalum Alloy

Additions of rhenium toughens tungsten but can embrittle tantalum. Therefore rhenium has the potential of embrittling the fusion weld nugget between tantalum and tungsten

BY GEORGE TARDIFF

ABSTRACT. Various approaches to electron beam welding a tantalum base alloy (T111) to a weldable tungsten base alloy (W-25at.% Re-30at.% Mo) were evaluated. Extreme solid solution strengthening and extensive cracking after cooling were observed in the weld nugget formed by welding the two alloys directly. "Braze welding" using fillers of Mo, Nb, and Mo-50 wt% Re resulted in substantial reductions in weld nugget hardness and reduced cracking somewhat. The cracking is attributed in part to the embrittling effect of rhenium in tantalum. The use of a pure molybdenum transition piece between the T111 and W-Re-Mo alloy was observed to result in the least fragile weldment partly because alloying between tantalum and rhenium is avoided. This technique would allow the use of weldments between the W-Re-Mo alloy and T111 in special cases.

Introduction

The potential desirability of combining a tungsten alloy structure with a tantalum alloy structure within the same space power system prompted the present study. The choice of tungsten alloys with their great high temperature strength potential for reactor liquid metal plumbing and a tantalum alloy for the generally more complex fabrications required for the conversion system would combine the best attributes of both alloy systems. The present study was therefore made to determine the feasibility of joining tungsten base alloys to tantalum base alloys using electron beam (EB) fusion welding.

It is expected that rheunium will be an additive in at least the early generation tungsten alloys requiring some fabricability, weldability and toughness. It was therefore desirable to choose a rhenium-containing alloy for the present study. The ternary solid solution alloy W-25 at.% Re-30 at.% Mo (W-25Re-30Mo) was chosen since it was known to be fabricable and weldable and also available in tubular geometry. The tantalum alloy chosen, T111 (Ta-8W-2Hf) is one of the most easily fabricated solid-solution strengthened Ta alloys.

G. TARDIFF is associated with Lawrence Livermore Laboratory, University of California, Livermore, California 94550. This work was performed under the auspices of the U.S. Atomic Energy Commission.

Materials and Experimental Techniques

Materials

The W-25Re-30Mo alloy was prepared by sintering the blended and compacted powders, hot extruding to a tube shell, and then warm drawing in a series of steps. The tubing selected was 0.5 in. in diameter with a 0.040-in. wall. Ta-8W-2Hf tubing of the same dimension was machined from an arc melted, swaged and annealed bar. Compositions of both the tungsten and tantalum alloy were within 0.25% of nominal and the sum of oxygen, carbon and nitrogen for each was less than 100 ppm. The other materials used, Mo-50Re, Mo, and Nb were nominally pure and of low interstitial content (O + C + N < 100 ppm). All of these were machined to the 0.5-in. diameter by 0.040-in. wall geometry for welding.

Welding

Electron beam welding was accomplished in a Hamilton Standard welding machine. Vacuum conditions at the commencement of welding were kept below 1×10^{-4} torr. Welding control parameters were established to give minimum energy for full penetration at 20 in./min surface speed. Having established the parameters, the actual weld was accomplished in two fusion passes at 100% penetration to promote homogeneity and reduce porosity in the weld nugget. Power levels at 100% penetration ranged from 90 kV—7 mA to 90 kV—10 mA. Beam precession at 60 cps to give a 0.020-in. diameter circle was used in all welding. Joint preparation was simple square butt, and slight tail stock pressure was used for pretacking. After tacking, the tail stock was removed and the fusion weld accomplished by rotation of the tube joint under the beam.

Braze welding was accomplished by carefully pretacking a thin (up to 0.018 in. thick) filler between the W alloy and Ta alloy tubes and proceeding as before.

Microprobe and Metallographic Analysis

Weld nugget compositions were determined by electron beam microprobe analysis for correlation with nugget hardness. Ten to twenty point counts were taken across a polished section, taken perpendicular to the weld axis. The resulting data are corrected for absorption, drift, deadtime and background.

Metallographic preparation was by standard techniques. Etching, however, was accomplished by argon ion bombardment since a simultaneous etchant for the W and Ta alloys could not be developed. The mounting procedure, which was the cause of some cracking, was by standard thermoplastic potting under 4000 psi at a minimum temperature of 70C.

Hardness

Diamond pyramid hardness (dph) testing was accomplished on polished sections taken transverse to the weld axis, using a 200-g load. Distance increments between hardness impressions were never less than five impression diameters.

Weldability of Component Alloys

Prior to the dissimilar alloy welding, an exhausitve study of the weldability of the W-Re-Mo alloy was completed. In this study, over 30 butt welds were made with no cracking observed. Furthermore, room temperature tensile tests of longitudinal specimens cut from welded tubes containing the weld in the gage length never failed in the weld nugget (weld was not dressed). Tensile elongation in these tests was never less than 0.2%. It was thus felt that the W alloy used represented a usefully weldable material. Weldments of T111 were already known to be tough and ductile.[1]

Results

Direct Weld Between W Alloy and Ta Alloy

Figure 1 shows a transverse section of the butt weld made directly between the W and the Ta alloys. Some of the severe transgranular cracking evident in Fig. 1 was observed on the surface of the as-cooled weld nugget. Most of the cracking, however, occurred during metallographic potting. Optical examination to 1000X, as well as all others made during this study, did not reveal the presence of second phase. Fractographs showed the cracking to be 100% cleavage. The small amount of porosity evident in Fig. 1 is believed to be incidental to the cracking.

Figure 2 shows the results of a hardness and microprobe analysis transverse across the weld nugget of Fig. 1. In Fig. 2a the hardness level of the weld nugget (820 ± 30 dph) is substantially higher than either of the component alloys (W alloy, 465 dph; Ta alloy, 240 dph). The microprobe traverse given in Fig. 2b shows that the composition of the weld nugget was quite uniform across the section. Tantalum and tungsten in nearly equiatomic composition make up about 75% of the atoms present at the nugget midpoint, with rheuium largely accounting for the balance. The very high hardness of the nugget is perhaps not surprising in view of the fact that substantial solid solution strengthening has been observed in the systems Ta-W[2] and Ta-Re.[3] The observation of cleavage could also be associated with the known tendency of relatively small additions of Re (~10 at.%) or W (~30 at.%) to Ta to promote cleavage failure at no reduction in area in single crystals.[2, 3]

Braze Weld With Mo

In an attempt to lower the hardness and improve the toughness of the weldment, an 0.018-in. thick Mo shim was fused between the W alloy and Ta alloy tubes. In Fig. 3 it is shown that the resulting weldment was more resistant to cracking that the direct weld. The single crack observed to be present in the as-cooled weldment may have propagated during potting.

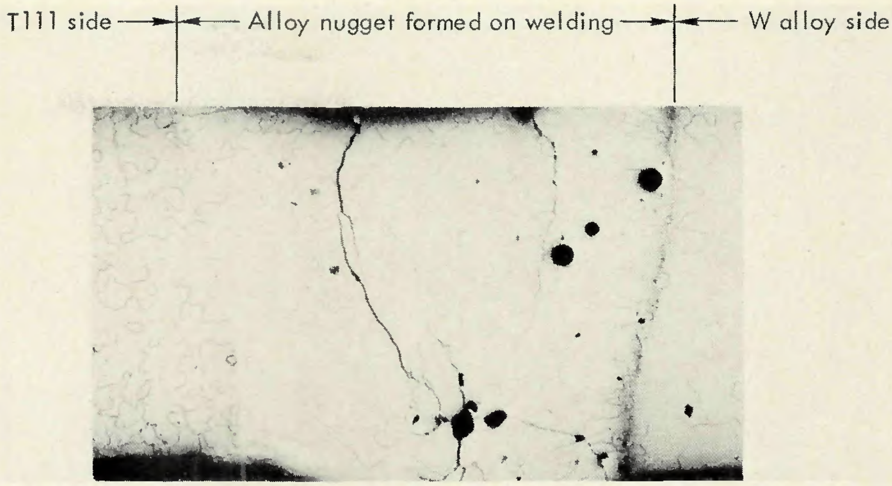


Fig. 1—Polished and cathodically etched transverse section of weld nugget made directly between W-25 at.% Re-30 at.% Mo and T111; 60X

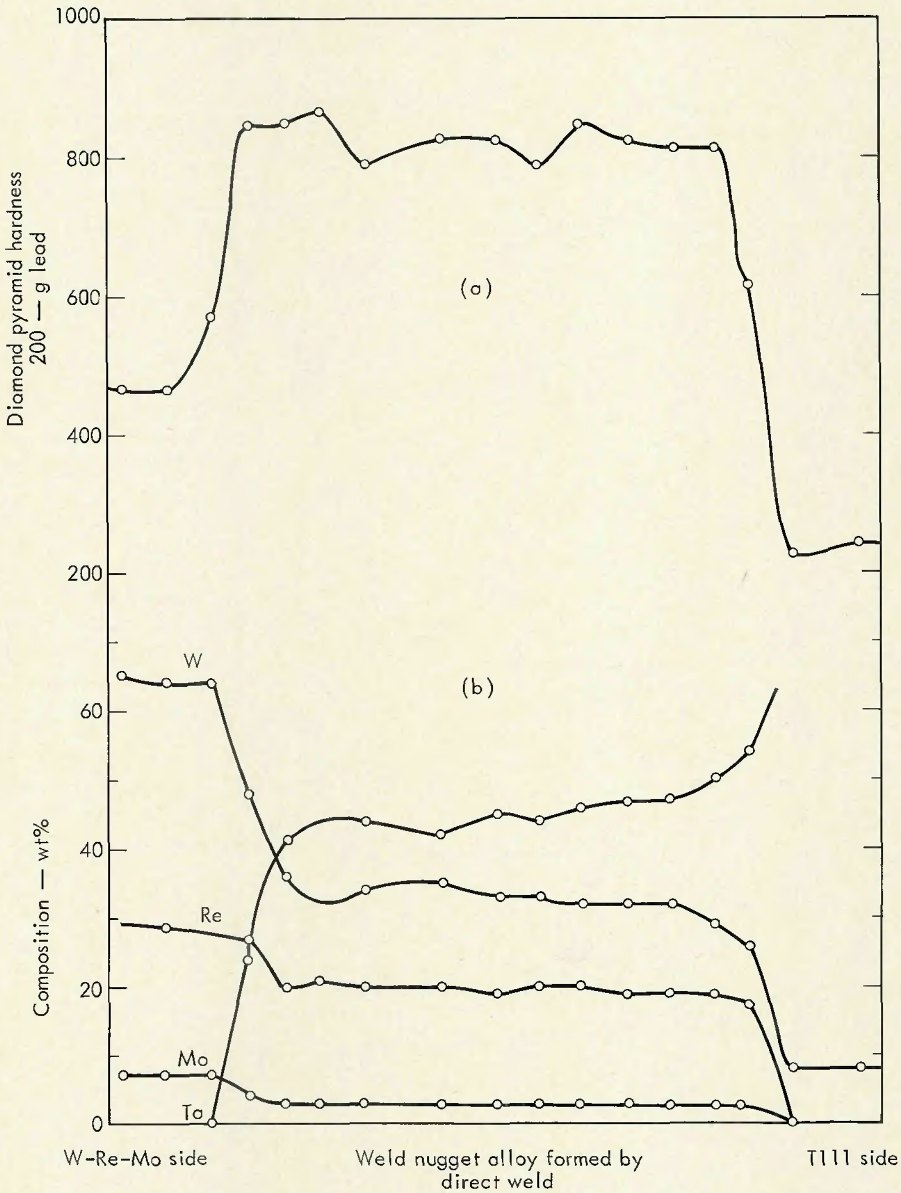


Fig. 2—Hardness (a) and microprobe analysis (b) transverse across direct weld between T111 (Ta-8 W-2 Hf) and W-25 at.% Re-30 at.% Mo (Note: Hf content neglected in microprobe analysis)

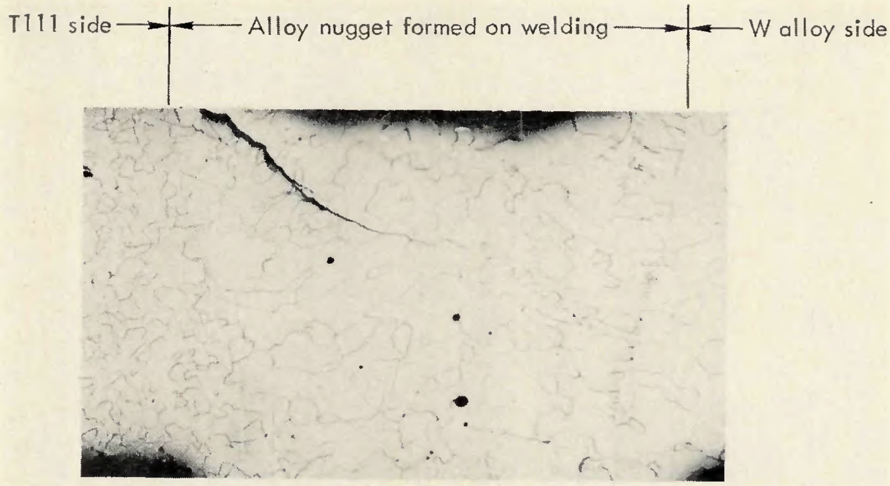


Fig. 3—Polished and cathodically etched transverse section of braze weld nugget made between W-25 at.% Re-30 at.% Mo and T111 with an interposed 0.018-in.-thick shim of pure molybdenum; 60X

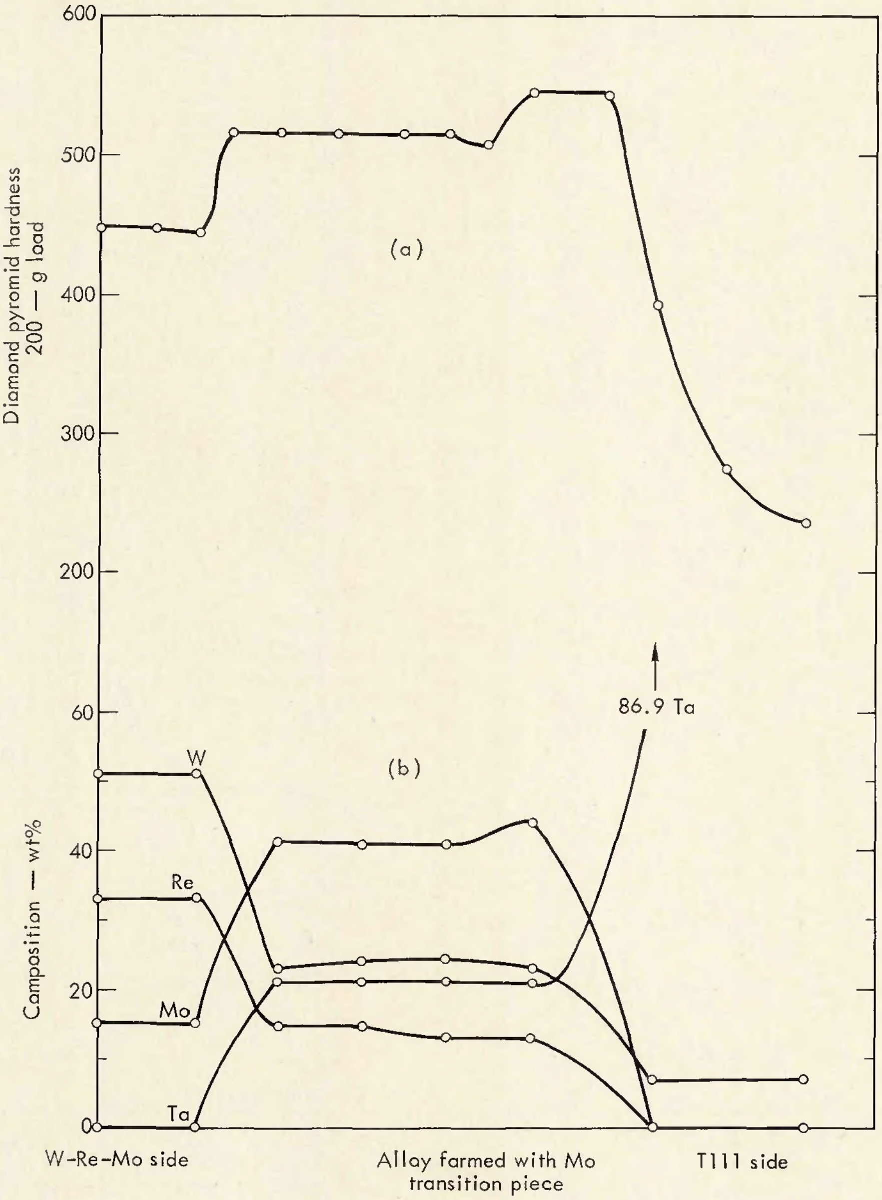


Fig. 4—Hardness (a) and microprobe analysis (b) traverse across a braze weld between T111 (Ta-8 W-2 Hf) and W-25 at.% Re-30 at.% Mo with an interposed 0.018-in.-thick shim of pure molybdenum.

In Fig. 4a, the hardness of the weld nugget (~530 dph) is shown to be appreciably lower than in the case of the direct weld (~820 dph). In Fig. 4b it is shown that good alloying and mixing had occurred in the braze weld, and that the presence of molybdenum had diluted the tungsten and tantalum to about 33% of the atoms present at the nugget midpoint. In addition, the rheunium level was considerably reduced relative to the direct weld.

Referring back to Fig. 3, it is observed that cracking had begun from the T111 side of the weld nugget. Figure 4b shows that Ta and Mo probably (as would be expected) made up the majority of atoms at this section with rheunium accounting for somewhat less than 10% of the atoms present. The observed cracking is perhaps understandable in view of the fact that low stress cleavage failure can occur in single crystals of tantalum alloyed with rhenium[3] and that some central compositions of the tantalum-molybdenum binary are brittle.[4]

Other Braze Welds

The results of all welds made and analyzed in the present study are summarized in Table 1 in terms of an average nugget hardness and composition at the nugget midpoint. In every case but one, the hardness was fairly uniform across the nugget and thus a single average represents a valid comparison value. The results of braze welding with a Mo-50Re shim are given in Table 1. In this case, the rhenium content of the nugget was increased to about 25at.% and the hardness of the nugget was moderate, ~600 dph. This weldment cracked through the center of the nugget on cooling from welding and had to be potted in two sections. The extreme fragility of this weld may, as before, be associated with the tendency of W, Mo and Re to embrittle Ta.

The results for a Nb shim braze weld also given in Table 1 suggests a somewhat tougher weld. Again, however, cracks developed during the relatively gentle potting procedure. As in the previous cases, the nugget was determined to be free of second phase (observable at 1000X) and cracking had been by cleavage. The cracking occurred on the W alloy-Nb side of the weld nugget.

Mo and Nb Transition Piece Welds

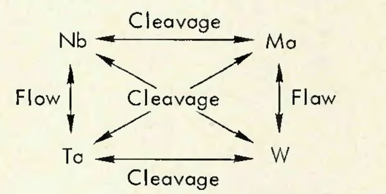
The observations made on welds made using a wide molybdenum transition piece are summarized in Table 1. In this weld the W alloy was first joined to a short length of pure Mo (1/4 in.), then the other end of the

Table 1—Summary of Welds and Analyses Made

Weld nugget alloy	Composition at. % at midpoint of weld nugget[a]	Weld nugget, dph hardness, 200-g load	Comments
Pure Mo	100 Mo[b]	210 ± 12	Coarse grain welds are brittle
T111	90 Ta, 8 W, 2 Hf[b]	240 ± 20	Weldments have essentially same properties as recrystallized parent alloy
W alloy	45 W, 25 Re, 30 Mo[b]	465 ± 20	Present work shows weldments of this alloy to have good ambient temperature properties
Alloy formed by welding T111 directly to W alloy	31.1 W, 5.6 Mo, 43.8 Ta, 18.5 Re	820 ± 30	Butt weld developed cracks during cooling after welding. Many more cracks developed during metallographic potting
Alloy formed by "braze welding" a 0.018-in. thick pure Mo shim between T111 and W alloys	17.6 W, 57.5 Mo, 15.4 Ta, 9.5 Re	530 + 14	Butt weld developed a through crack during cooling after welding
Alloy formed by "braze welding" a 0.018-in. thick Mo-50 wt % Re shim between T111 and W alloys	19.0 W, 33.2 Mo, 23.3 Ta, 24.5 Re	600 ± 22	Butt weld developed a through crack during cooling after welding
Alloy formed by "braze welding" a 0.010-in. thick pure Nb shim between T111 and W alloys	18.8 W, 12.0 Mo, 38.4 Ta, 11.3 Re, 19.5 Nb	708 ± 20	Cracked during metallographic potting procedures on the W alloy side of the nugget
Alloy formed by welding W alloy directly to pure Mo	No plateau, about linear in composition and hardness from pure Mo to the W-Re-Mo alloy		Survived both welding and metallographic potting without cracking
Alloy formed by welding T111 alloy directly to pure Mo	4 W, 56 Mo, 40 Ta	508 ± 18	The Mo to T111 joint cracked during an attempt to load a successfully fabricated tensile specimen into grips
Alloy formed by welding W alloy to pure Nb	—[c]	—	On preparation for EDM machining W alloy to Nb weld nugget fractured
Alloy formed by welding T111 alloy to pure Nb	—	—	

[a] All welds referred to made by electron beam process in 0.5 in. o.d. × 0.040 in. wall tubular geometry
[b] Nominal compositions, all others by microprobe analysis neglecting Hf content
[c] Not determined

V	VI
At. No. 40 Rod. 143 Wt. 929 $\boxed{Nb}$ BCC M.P. 2415 $4p^6\ 4d^4 5s$	At. No. 41 Rad. 136 Wt. 95.9 $\boxed{Mo}$ BCC M.P. 2622 $4p^6\ 4d^5 5s$
At. No. 73 Rod. 143 Wt. 180.9 $\boxed{Ta}$ BCC M.P. 2996 $5d^3 6s^2$	At. No. 74 Rad. 137 Wt. 183.9 $\boxed{W}$ BCC M.P. 3395 $5d^4 6s^2$



Mechanical behavior near 1:1 compositions

Fig. 5—Part of the periodic table showing data for Nb, Mo, Ta and W; the lower scheme shows mechanical behavior of alloys of 1:1 atomic ratio, after Van Thorne, L. E., and Thomas, G.; ref. 4

Mo was welded to the T111 in a second operation. We used this approach to avoid alloying between rhenium and tantalum. The alloy nugget formed between the Mo and W alloy did not crack and the alloy nugget formed between the T111 and Mo survived cooling and EDM machining and finally cracked during loading into tensile grips. This weld nugget was more resistant to cracking than previous ones containing tungsten and rhenium in addition to the molybdenum and tantalum. It is significant in this connection that this alloy nugget had the lowest hardness (508 dph) of any of the weld nugget alloys examined in the present study.

A Nb transition piece weld was made in a manner similar to that of the Mo transition piece weld. As in the case of the Mo transition weld, this new weldment seemed more resistant to cracking than any of the braze welds. Still, with reasonably gentle handling during preparation for machining, a crack did develop in the nugget formed between the Nb and W alloy.

Discussion

Figure 5 taken from reference 4 summarizes the behavior exhibited by binary alloys formed between the group V elements Nb and Ta and the group VI elements Mo and W. Low ductility cleavage failure is known to occur for central binary alloy compositions made from combinations of elements across the groups. In each of these cases, this embrittlement is associated with extreme solid solution strengthening and high yield strength.

Figure 6 summarizes in a convenient way the strengthening data taken from Table 1 of the present study. In the case of the weld nuggets containing tungsten and rhenium, the hardness seems to correlate well with the proportion of tantalum in the weld nugget. It is also interesting that the two points for the alloys not containing tungsten or rhenium fall about equally below the former curve. The upward sweeping slope of the curve in Fig. 6 is similar to the strength-composition dependence observed in the case of solid solution strengthening in the Ta-Mo system.[4] The data are fewer, but the strength of the dependence for Ta-W alloys[2] is similar to that for Ta-Mo alloys. It seems rea-

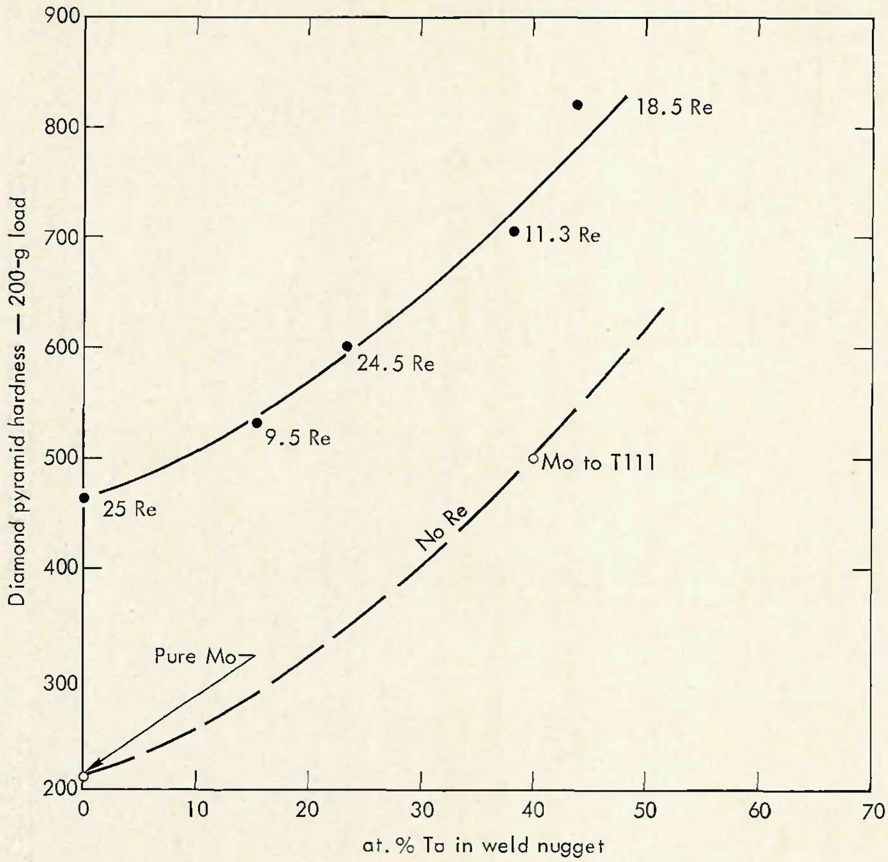


Fig. 6—Correlation between Ta content and weld nugget hardness for welds made in present study.

sonable to conclude, therefore, that the pronounced strengthening observed in the present study is substantially due to solid solution alloying across the groups. The fact that cleavage cracking was observed on the mixed group side of the transition pieces is consistent with this.

The curves in Fig. 1 suggest that the addition of rhenium to the weld nugget substantially increases its hardness. In addition, the apparent ease of cracking of the nugget formed with the Mo-50Re shim and the apparent difficulty in cracking the nugget formed by welding pure Mo directly to T111 suggests that the effect of rhenium is to embrittle the nugget. The apparent degrading effect of rhenium in the present case could have its basis in the potent effects rhenium additions are known to exert on Ta-Re single crystals. The addition of ~10 at.% rhenium to tantalum, for example, leads to nil ductility cleavage failure of single crystals tensile tested at room temperature.[3] Also, the Ta-base Re system exhibits the strongest solid solution strengthening of any of the refractory metal solution systems investigated to date. It is not surprising then that the least fragile weldment in the present study was made by avoiding alloying between rhenium and tantalum.

Conclusions

The present work shows that it is not possible to produce useful fusion welds directly between the alloy W-25 at.% Re-30 at.% Mo and T111. The difficulty is rooted in the basic properties of solid solutions formed between the group V elements Nb and Ta with the group VI elements Mo and W. These are the pronounced strengthening and embrittlement which occurs for alloys with central alloy compositions. The embrittling effect of rhenium additions on tantalum also contribute to the problem of producing useful welds. This is a very fundamental problem in the making of successful W alloy to Ta alloy welds directly between each other because rhenium additions are required to produce fabricable, tough alloys of tungsten.

The use of Mo as a transition-piece between the Ta alloy and W alloy substantially lowered the hardness of the weld nugget formed. The resulting weldment was much less fragile than weldments made by directly fusing the alloys or braze welding. This improvement would allow the production of weldments in special cases. Even here, however, the basic brittleness of the element combinations involved will severely constrain the use of such weldments at or below room temperature.

References

1. Lessmann, G. G., Weld. Jnl. 45, 540-S—560-S (1966).
2. Ferriss, D. P., Rose, R. M., and Wulff, V., Trans. AIME, 224, 584-588 (1962).
3. Raffo, P. L., and Mitchell, T. E., Trans. AIME, 242, 907-917 (1968).
4. Van Torne, L. I., and Thomas, G., Acta Met., 14, 621-635 (1966).