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61-4-6
NOX

August 4, 1961

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Bureau of Naval Weapons
Department of the Navy
Washington 25, D. C.

Attention: RRMA-231

Via: Inspector of Naval Material
10 North 8th Street
Reading, Pennsylvania

Subject: Bureau of Naval Weapons, Department of the Navy
Contract NOW 61-0410-c
Ultrasonic Welding of Refractory Metals
Progress Report No. 2

*Now 61-0410C
(RRMA)*

ASTIA

OCT 16 1961

Gentlemen:

In accordance with the referenced contract, this letter constitutes the second progress report covering the work done during the period May 1 through May 31, 1961.

MATERIALS

A. Niobium-10% Molybdenum-10% Titanium (D-31 Alloy)

A correction is hereby made to Table 1 and the fourth paragraph, page 2, of Progress Report No. 1. The carbon content of this alloy as now furnished is 1000 ppm, rather than 60-100 ppm as stated in Progress Report No. 1. All other property values listed in Table 1, however, including the embrittlement temperature of 2900°F, are correct as listed.

At the end of this period, based on the preliminary welding experiments described below, an order was placed for ten square feet of D-31 alloy in gages ranging from 0.005-in. to 0.020-in., with the largest portion being of 0.010-in. thickness.

B. Tungsten

In addition to the one square foot each of 0.005-in. and 0.010-in. tungsten sheet obtained from the Fansteel Corporation and listed in Table 1, Progress Report No. 1, one square foot of 0.010-in. sheet was received from the General Electric Company.

The material from both sources appears, from visual inspection, to be essentially identical. Both exhibit negligible room temperature ductility compared with a shipment of 0.010-in. tungsten recently received in connection with other work. This third lot exhibited appreciable ductility, amounting to about 2%, as estimated by manual bending. The latter material also originated from Fansteel Metallurgical Corporation and their regional

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Bureau of Naval Weapons
August 4, 1961
Page Two

representative was consulted regarding this difference in the materials. It was determined that the material purchased directly for this program was furnished in the "as-rolled" condition, while the more ductile sheet had been furnished by the manufacturer as "stress-relief annealed". These two "conditions" would partially explain the difference in room temperature ductility, although it must also be recognized that small variations in content of certain impurities such as oxygen have a large effect on this property.

Future orders for tungsten sheet will specify the "stress-relief annealed" condition; meanwhile, inquiries are being made about having the material on hand annealed locally.

DETERMINATION OF WELDING MACHINE SETTINGS

A. Estimation of Threshold Energy and Optimum Clamping Force for Welding Arc-Cast Molybdenum - 0.5 Titanium

An investigation was made on 0.005-in. and 0.010-in. arc-cast Mo-0.5 Ti, using the technique of weld evaluation by peeling described on page 9 of Progress Report No. 1.

On the 0.005-in. arc-cast material, welds were made at power levels of 800, 1000, 1200, and 1400 watts (electrical power to the transducers) and at clamping force settings ranging from 100 lb to 700 lb, the pulse time being held constant at 0.6 sec.

The optimum clamping force range was found to be 300 to 350 lb, the same as that found for 0.006-in. powder-metallurgy Mo-0.5 Ti*. At this clamping force, the minimum power required to obtain nuggets when the weld is peeled was found to be 1000 watts, which corresponds to an energy of 600 watt-seconds. The minimum energy for the powder metallurgy product was about 475 watt-seconds.

The 0.010-in. arc-cast material was welded at power levels of 1000, 1500, 2000, and 2500 watts, over a clamping force range of 100 to 800 lb, again using a constant pulse time of 0.6 sec. Unlike the 0.006- and 0.011-in. powder metallurgy products and the 0.005-in. arc-cast sheet, this 0.010-in. material did not peel complete nuggets when welded at the higher power levels, the separation being a partial nugget corresponding to the "moderate weld" appearance of Type "B" on page 9 of Progress Report No. 1. This may be another indication of the superior cross-laminar strength of the arc-cast material rather than being indicative of inferior weld quality to that obtained in the powder metallurgy product.

* See Fig. 3, Progress Report No. 1 of this contract.

Bureau of Naval Weapons
August 4, 1961
Page Three

The minimum energy required to get partial nugget peeling in the 0.010-in. arc-cast sheet was about 600 watt-seconds at a clamping force of 400 lb. Unlike the 0.011-in. powder metallurgy material evaluated previously*, this threshold energy rose sharply when the clamping force was varied by only 100 lb in either direction from 400 lb.

It should be emphasized that this minimum energy condition (i.e., 1000 watts applied for 0.6 sec to produce nuggets in 0.005-in. and partial nuggets in 0.010-in. material) is not expected to be the one which produces the best welds. Rather, it establishes the approximate optimum clamping force and thereby furnishes a basis for the next step in the investigations: statistically designed experiments with various combinations of power and pulse time at energy levels higher than the minimum.

B. Investigation of Machine Settings for D-31 Alloy

The Nb-10 Mo-10 Ti alloy (D-31) proved to be much more difficult to weld than the Mo-0.5 Ti alloy, at least with the conventional single-pulse type of welding cycle investigated during this period. Preliminary investigations made during this period, with the limited quantity of material on hand, included welding trials on 0.005-in. and 0.008-in. sheet and weld zone temperature measurements in 0.020-in. sheet.

1. Welding of 0.005- and 0.008-in. D-31 Alloy

Numerous attempts were made to weld both 0.005- and 0.008-in. D-31 at powers ranging from 800 to 3000 watts, pulse times from 0.3 to 1.5 sec, and clamping forces from 100 to 900 lb. Throughout most of this range the weldments exhibited only moderate sticking when peeled.

Some degree of success was finally obtained with 0.008-in. sheet using machine settings of 3000 watts/700 lb/1.0 sec with the clamping force maintained for 2.0 sec after the end of the ultrasonic pulse. Several specimens were also made with 0.0005-in. pure nickel interleaf. One specimen of each type was tested in tensile-shear, the non-interleaf weld having a strength of 43 lb, and the interleaf weld a strength of 84 lb. Other specimens were examined metallographically as discussed later.

2. Measurement of Temperature Rise in the Weld Zone Using 0.020-in. D-31 Alloy

On page 6 of Progress Report No. 1, it was explained that the clamping force which effects the best impedance match between the machine and the weldment (and therefore the most efficient delivery of energy into the weldment) corresponds to the force at which the greatest temperature rise occurs in the weld zone. Accordingly, temperature measurements were made in the weld zone between 0.020-in. sheets of D-31 alloy with the power and pulse

* See Fig. 4, Progress Report No. 1 of this contract.

Bureau of Naval Weapons
August 4, 1961
Page Four

time being held constant at 1500 watts and 0.6 sec. This energy is well below that required to weld this thickness, but should be sufficient to indicate the force value for best impedance match. Figure 1 is a plot of these temperature-rise values as a function of clamping force.

The D-31 alloy may be an exception to the hardness-thickness-welding energy relationship discussed on page 4 of Progress Report No. 1. An energy of 3000 watt-seconds was required to obtain a weld in 0.008-in. material, compared with the predicted energy requirement of 870 watt-seconds. No explanation for this apparent anomaly is presently available, but it will be studied further when more D-31 material is obtained.

METALLOGRAPHIC EVALUATION OF WELDS

Metallographic studies were made of welds obtained in 0.005-in. Mo-0.5 Ti and in 0.008-in. D-31.

Figure 2a is a micrograph of the cross section of a single-spot weld in 0.005-in. arc-cast Mo-0.5 Ti, welded at a machine setting of 1100 watts/350 lb clamping force/0.6 sec. Figure 2b is a portion of the same weld photographed at higher power. The bond is good and of uniform quality over the entire section, a high degree of internal plasticity having been achieved which completely eliminated the original interface. There is no evidence of recrystallization in the area where the plastic flow occurred.

Figure 3 is a micrograph of a portion of the weld between sheets of 0.008-in. D-31 alloy without using interleaf. Many areas of the section are in intimate contact, but the general lack of turbulence and transfer of material across the interface indicates that a low fraction of the input energy (3000 watt-seconds) is being utilized in the weld zone, and this may help explain the present lack of correlation with the hardness-thickness-energy equation.

FUTURE WORK

For the next report period, the work planned includes:

1. Exploratory welding of tungsten sheet to determine machine settings.
2. Further evaluation of welding Mo-0.5 Ti by means of statistically designed experiments and tensile-shear test evaluation.
3. Further investigation of the problem of imparting a greater fraction of the energy supplied to the transducers into the D-31 alloy weldment.

Very truly yours,

C. R. Frownfelter
C. R. Frownfelter
Senior Engineer-
Staff Assistant

CRF:ss

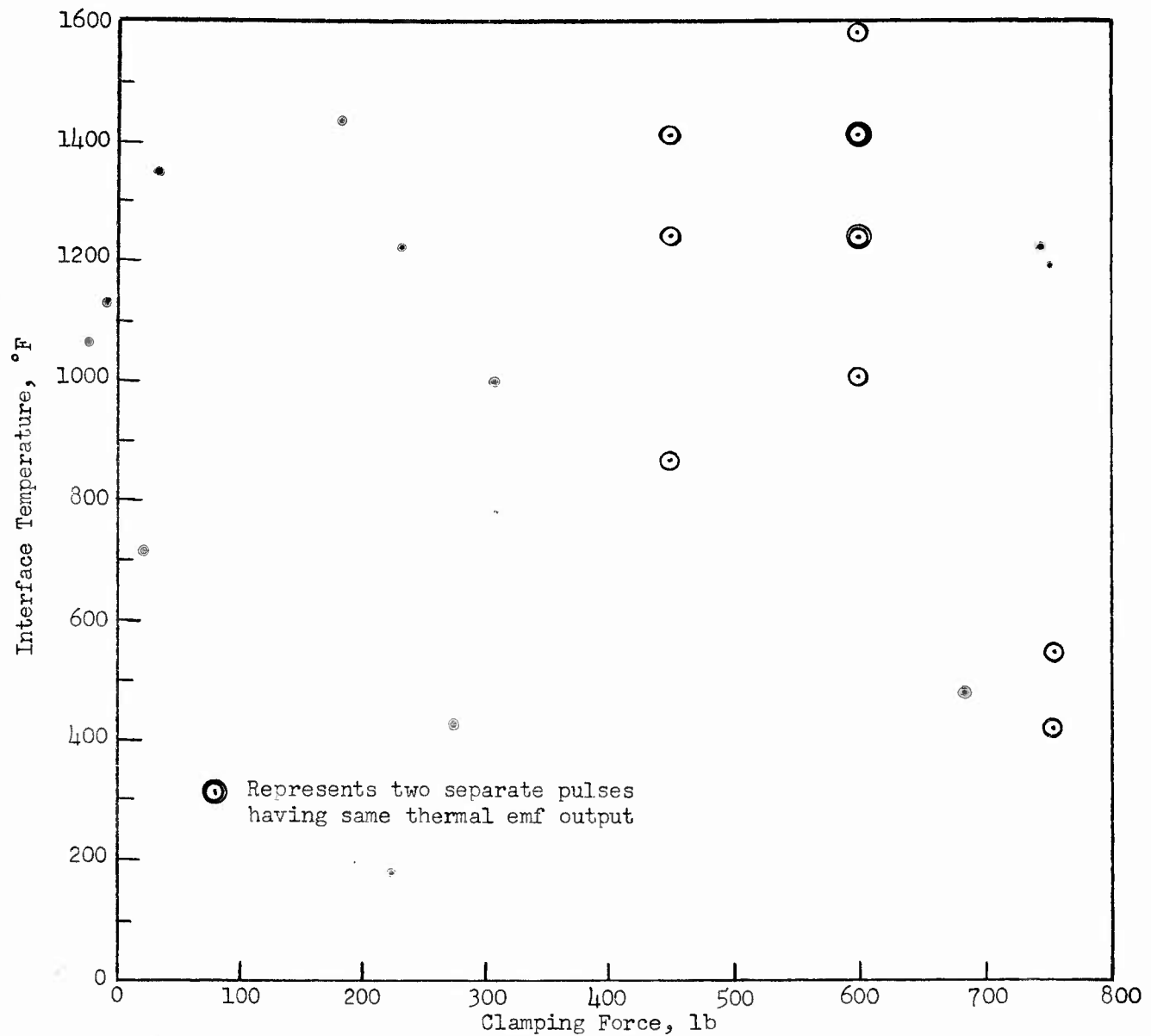
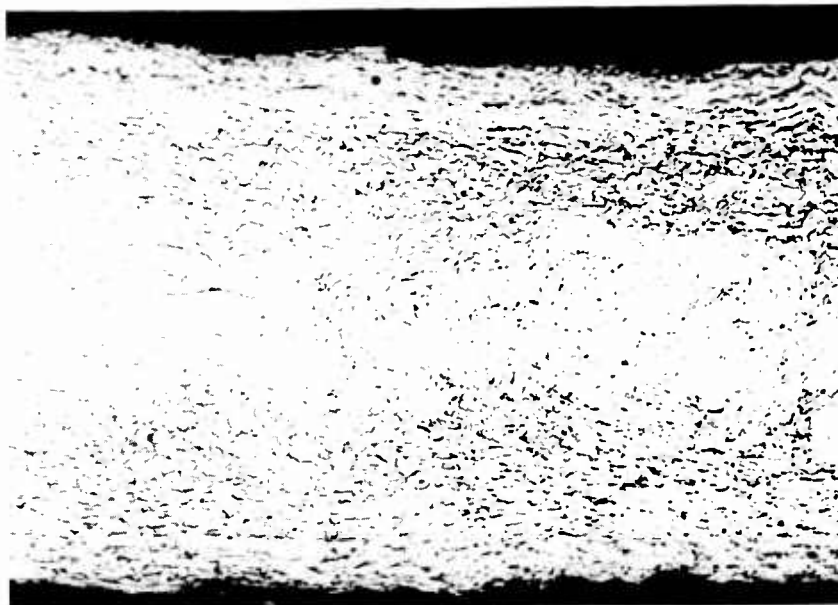


Fig. 1: TEMPERATURE RISE IN THE WELD ZONE AS A FUNCTION OF CLAMPING FORCE WHILE WELDING 0.020-INCH NIOBIUM-10% MOLYBDENUM-10% TITANIUM ALLOY (Du Pont D-31 Alloy)

Sonotrode Tip Material and Contour: Astroloy, 3-in. spherical radius

Welding Power: 1500 watts (this level below minimum for welding)

Weld Time Interval: 0.6 sec



a. Magnification: 200X



b. Magnification: 500X (portion of a. area)

Fig. 2: PHOTOMICROGRAPHS OF ULTRASONIC WELD BETWEEN TWO SHEETS
OF 0.005-INCH ARC-CAST MOLYBDENUM-0.5 TITANIUM

Power: 1100 watts
Clamping Force: 350 lb
Weld Time: 0.6 sec
Etch: KOH + $K_3Fe(CN)_6$

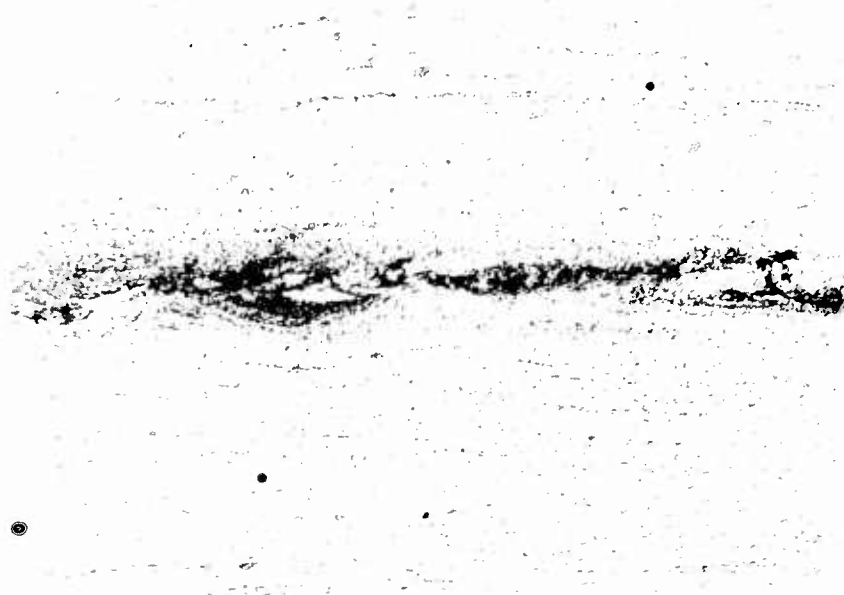


Fig. 3: PHOTOMICROGRAPH OF ULTRASONIC WELD BETWEEN SHEETS
OF 0.008-INCH NIOBIUM-10% MOLYBDENUM-10% TITANIUM
(Du Pont D-31 Alloy)

Etch: 10 p HF, 30 p HNO_3 , 50 p Lactic Acid

Magnification: 500X

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