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January 24, 1962

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NAVAL WEAPONS

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

Attention: BRMA-231

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

Subject: ULTRASONIC WELDING OF REFRACTORY METALS  
Progress Report No. 5  
For the period, 1 October through 30 November 1961  
Bureau of Naval Weapons, Department of the Navy  
Contract NOW 61-0410-c



Gentlemen:

During the period, 1 October through 30 November 1961, the experimental work and other related activities proceeded along the following lines: the reproducibility of weld strength values for 0.005- and 0.010-inch Mo-0.5Ti as well as the quality of these bonds were evaluated; in one case, the effect of foil interleaf was investigated; limited shear-strength studies were also made with 0.005-inch Cb(D-31); and the feasibility of using ultrasonics to determine weld integrity is being explored. The results of this work are summarized herein.

MOLYBDENUM-0.5 TITANIUM STUDIES

0.010-INCH MATERIAL

As reported previously\*, examination of 0.010-inch Mo-0.5Ti specimens (welded at the MEC of 0.6 second, or 1080 watt-seconds) after tensile-shear testing, disclosed a lesser degree of metal interpenetration at the weld interface than that noted for bonds in 0.005-inch sheet. Accordingly, this situation was explored further at higher power levels and/or longer weld intervals.

Some specimens of the 0.010-inch material were welded at an input power of 3.0 kw and weld intervals of 0.6-, 0.8-, and 1.0-seconds, while others were joined at a higher power level, 3.6 kw, and weld intervals of either 0.5- or 0.8-seconds; a clamping force of 400 pounds was used in both series of welds.

\* ULTRASONIC WELDING OF REFRACTORY METALS, Progress Report No. 3, October 1961.

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On the basis of tensile-shear tests, a 400-pound clamping force, 3.0-kw input power and a 0.8-second weld interval were selected as the best conditions for welding 0.010-inch Mo-0.5Ti.

One specimen, welded at each power, weld-interval combination was also examined by the planar (parallel)-sectioning method described previously\*. During the grinding process, radial discontinuities in the bottom sheet (relative to the sonotrode tip) were disclosed in three of the five specimens; these flaws were located below the weld interface but within the projected weld envelope area. Only one of the five specimens was welded at the conditions now considered best for joining this material.

In order to investigate the matter of weld integrity and methods for detecting discontinuities more thoroughly, two additional groups of specimens were prepared using the above welding conditions. In one group, the specimen size was 1/2- x 2-inches while in the other, the coupons were 3/4- x 3-inches. All but 10 of these were used in the weld integrity <sup>®</sup> studies discussed later in this report. With the other 10 specimens, tensile-shear tests were made. Compared with previous tensile-shear measurements, meticulous care was exercised to minimize slippage and misalignment of the specimens in the jaws of the Instron Machine (with the very hard, refractory metals, the grip of the steel-faced jaws must be carefully adjusted to prevent pressure cracking; consequently, the pressure exerted may not be sufficient to hold the specimens securely.) The results of these tests are summarized in Table 1; for purposes of comparison, similar data from Table 2 Progress Report No. 3 are also included in this table.

While the three averages noted in Table 1 are not statistically different, the trend toward higher strength values shown therein may be highly significant. When this trend and the decrease in variability of the latest measurements, as indicated by the relative standard deviation, are considered together, there is little doubt that this improvement can be attributed to both the change in welding conditions and the use of an abrasive to ensure a firmer grip on the specimen during tensile-shear tests. Because of the limited amount of data available, however, the relationship between specimen size and shear strength variability could not be ascertained.

In the final evaluation of Mo-0.5Ti welds, a larger number of specimen will be tested to establish, with a high degree of reliability, both the strength and reproducibility of such bonds. Furthermore, aluminum support strips will be cemented to each specimen before tensile-shear tests are made in order to provide a firm grip between the specimen and the jaws of the Instron Machine.

#### 0.005-INCH SHEET PLUS INTERLEAF

Since an interleaf of thin foil has been used successfully in the past to increase the weld strength and to reduce the susceptibility of the parent material to cracking during welding, the applicability of this

\* ULTRASONIC WELDING OF THE REFRACTORY METALS, Progress Report No. 4,  
November 1961.

Table 1

SUMMARY OF TENSILE-SHEAR DATA FOR 0.010-INCH MO-0.5Ti

Clamping Force: 400 pounds

Sonotrode Tip: Astroloy, spherical, 3-inch radius

Specimen Size (inch)	Gripping Method	Welding Conditions			Tensile Shear Strength		
		Power (kilowatts)	Weld Interval (seconds)	Energy (kilowatt-seconds)	Measurements (number)	Average Strength (pounds)	Rel. Std. Deviation** (percent)
1/2 x 1/2	Steel Test Jaws	1.8	0.6	1.08	6	77	41
1/2 x 2	Abrasive Between Jaws and Specimen	3.0	.8	2.4	5	85	21
3/4 x 3	Abrasive Between Jaws and Specimen	3.0	.8	2.4	5	103	25

\* From Table 2, ULTRASONIC WELDING OF REFRACTORY METALS, Progress Report No. 2, August 1961.

\*\* Same as coefficient of variation.

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technique to the refractory metals was investigated using 0.005-inch Mo-0.5Ti and 0.0005-inch foils of unalloyed titanium and tantalum. Titanium was included in this initial study because, under certain circumstances, it performs surprisingly well for short periods at high temperatures.

All specimens were welded at 1000-watts input power, 300-pounds clamping force, and a weld interval of 0.6 seconds. Of these, 10 were welded without interleaf (to serve as controls) while the remainder were joined with either 0.005-inch AMS 4901B unalloyed titanium foil or 0.0005-inch tantalum sheet. As shown in Table 2, the average tensile-shear strengths for the three groups of specimens were essentially the same. However, the variability (i.e. relative standard deviation) of the data for titanium and tantalum interleaf specimens, was nearly 50 percent less than that for the control (non-interleaf) welds.

Additional specimens were welded at a power level of 1200 watts and examined by the planar-sectioning method. Due to the difficulties encountered in parallel (planar)-sectioning the test coupons, only one specimen of each type (i.e. no interleaf, titanium and tantalum interleaf) was examined; the bottom sheet of the control specimen was lost during grinding operations. While the top sheet of the titanium interleaf coupon was free of flaws, the bottom sheet of this specimen, as well as the top sheet of the control and both pieces of the tantalum interleaf coupon exhibited internal discontinuities.

The planar-sectioning method requires the use of metallographic preparation procedures and is, therefore, exceedingly time-consuming. Although this procedure is the most reliable of the presently available methods, several shortcomings, especially when sectioning thin gage (~0.005-inch) material, are evident -- warpage of the specimen during welding results in non-uniform removal of material during grinding and the thin sheet is easily dislodged from the mounting medium. A more rapid method for determining weld integrity is essential; at present, however, an alternate method for studying weld quality is not available and considerable development effort will be required to evolve a fast and reliable procedure for this purpose.

#### COLUMBIUM (D-31) ALLOY STUDIES (0.005-INCH)

Welding conditions for joining 0.005-inch Cb(D-31) were established at a weld interval of 0.5 second, an input power of 750 watts and a clamping force of 300 pounds. The average shear strength of five specimens welded under these conditions, was 41 pounds and the variability was approximately 20 percent. Since these results are comparable to those achieved with tantalum interleaf coupons of 0.005-inch Mo-0.5Ti (see Table 2) further metallographic studies of the Cb(D-31) bonds were made. Neither the continuity nor the degree of bonding, however, was significantly different from that obtained previously\*..

\* ULTRASONIC WELDING OF REFRACTORY METALS, Progress Report No. 3, Figure 3, August 1961.

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Table 2

EFFECT OF FOIL INTERLEAF ON THE TENSILE-SHEAR  
 STRENGTH OF 0.005-INCH MO-0.5TI WELDS

Welding Conditions:

Input Power - 1000 watts  
 Clamping Force - 300 pounds  
 Weld Interval - 0.6 second

Sonotrode Tip:

Material - Astroloy  
 Type - Spherical  
 Radius - 3 inch

Interleaf Material	Gage (inch)	Tensile-Shear Strength		
		Measure- ments (number)	Average Strength (pounds)	Rel. Std. Deviation* (percent)
None	--	10	45	38
Titanium (AMS 4901B)	0.0005	7	42	22
Tantalum	.0005	8	43	21

\* Same as coefficient of variation.

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The results of other work now in progress, however, indicate that an adequate bond can be produced in Cb(D-31) by increasing the input power.

#### WELD INTEGRITY STUDIES

Thus far in the experimental work, weld envelopes exhibiting the characteristic of high internal plasticity and surface interpenetration, have been obtained with Mo-0.5Ti and in tungsten. For many materials, the ultrasonic spot-weld assumes an annular configuration such as that shown in Figure 1A. This photograph was taken of one sheet of a Mo-0.5 Ti weldment after the weld was fractured in tensile-shear test. The weld pattern shown in Figure 1B, however, is more typical of those obtained in the welding studies thus far -- this pattern shows the random distribution of bonded regions in the envelope area.

Inconsistencies in the weld pattern, lack of adequate integrity, and the variability of the weld strengths are undoubtedly interrelated and probably can be attributed to the fluctuations in the power delivered into the weld zone during a particular interval of time. This may result from time variations in the tip-weldment coupling. Also, energy is absorbed in the formation of internal discontinuities which, in turn, adversely affect the integrity of the weld.

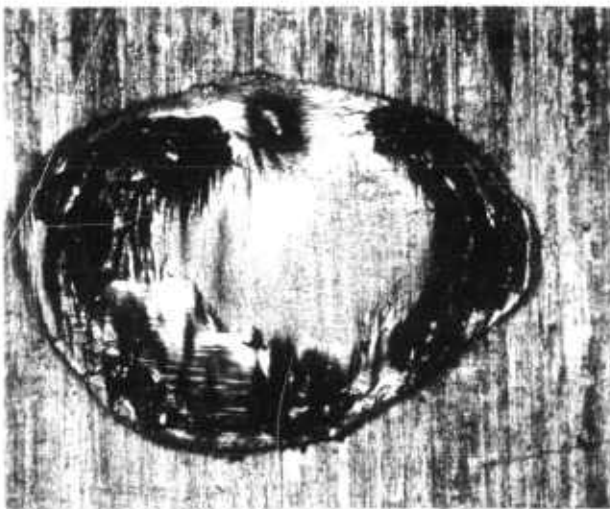
#### ACOUSTIC ENERGY INVESTIGATIONS

In an effort to resolve these problems, a method based on the SWR (Standing-Wave Ratio) principle developed previously\* was utilized to estimate changes in vibratory energy input to the weldment as a function of the tip displacement. A single sensing-element was located on one of the wedge-reed type couplers at a point where its output corresponds to the minimum longitudinal particle displacement in the coupler. In this position, the deflection signal, which is recorded on a strip chart, is related to the rate of vibratory energy delivery into the weldment. Although this signal alone does not indicate the power delivered by the sonotrode tip, changes are indicative of variations in the welding conditions.

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\* Jones, J. B., et al, "Fundamentals of Ultrasonic Welding - Phase I", RR-59-105, Final Report, Navy Contract NOas-58-108c, 1959 (May).

Jones, et al, "Fundamentals of Ultrasonic Welding - Phase II", RR-60-89, Final Report, Navy Contract NOas-59-6070-c, 1960 (August).



A. Annular Weld Area Characteristic of Ultrasonic Bonds



B. Random Distribution of Bonded Areas In Weld Envelope

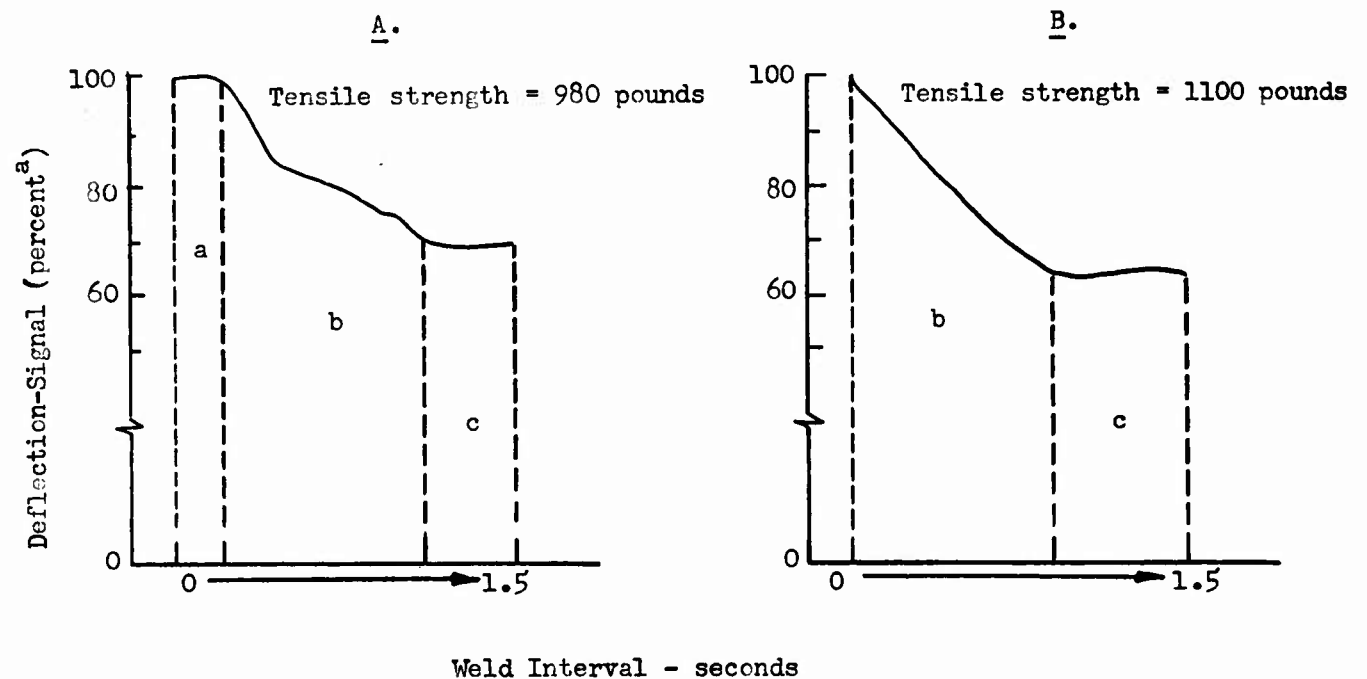
Figure 1: TYPES OF WELD PATTERNS FORMED IN 0.005-INCH Mo-0.5Ti

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Typical deflection-signal (percent of maximum deflection) recordings for 0.040-inch 2024-T3 aluminum are shown in Figures 2A and 2B.

Figure 2

DEFLECTION-SIGNAL RECORDINGS FOR 0.040-INCH 2024-T3 ALUMINUM



a. Percent of maximum deflection

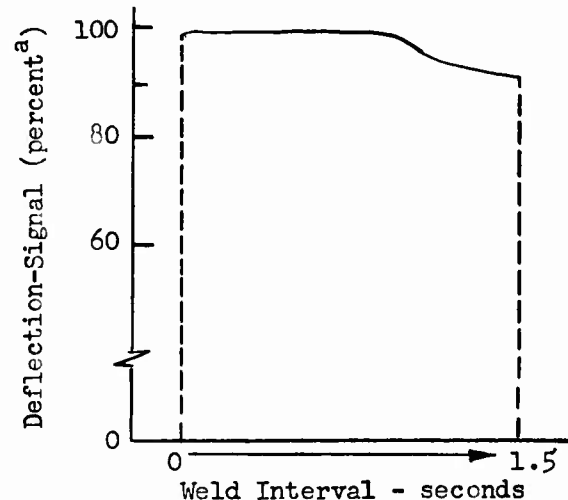
In Figure 2A, the deflection signal is near the maximum during the initial portion of the weld interval (region "a"). This is attributed to a brief "pre-coupling" period during which essentially all the power delivered is dissipated as heat due to sliding friction between the tip and the weldment or between the weldment sheets. The residual power is probably expended in accelerating the displacement of the tip member. Region "b", where the deflection is decreasing, is attributed to the vibratory coupling of the sonotrode to the weldment. The final phase, region "c", is characterized by a constant displacement at a minimum level, thus indicating that the coupling

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process is complete. Force-power programming will effectively control region "a", and, as reported by G. E. Hanford\*, the beginning of region "b" is the point at which weld time can be controlled.

Another situation, in which the coupling process begins as soon as power is applied, is presented in Figure 2B. A curve shaped like that of Figure 2B is also characteristic of the type obtained with 0.025-inch 302 annealed stainless steel. While this latter situation is believed to be the most desirable, curves of both types have been obtained with aluminum specimens that exhibited tensile-shear strengths in the range of 800 to 1200 pounds. On the other hand, curves such as that depicted in Figure 3 are typical of low strength welds in aluminum where the strength was below 800 pounds. (This curve was obtained by driving the welder at other than its resonant frequency).

Figure 3  
 0.040-INCH 2024-T3 ALUMINUM  
 (Tensile strength = 650 pounds)



<sup>a</sup> Percent of maximum deflection.

The three deflection-signal curves of Figure 4 were obtained while welding 0.005-inch Mo-0.5Ti (1200 watts, 300 pounds, 0.6 seconds). These welding conditions are the same as those used for the study summarized in Table 1 of Progress Report No. 4 where the average tensile strength was 56 pounds. Curve A indicates that coupling was delayed until the last 0.1 second of the weld interval -- consequently, the specimen was not bonded.

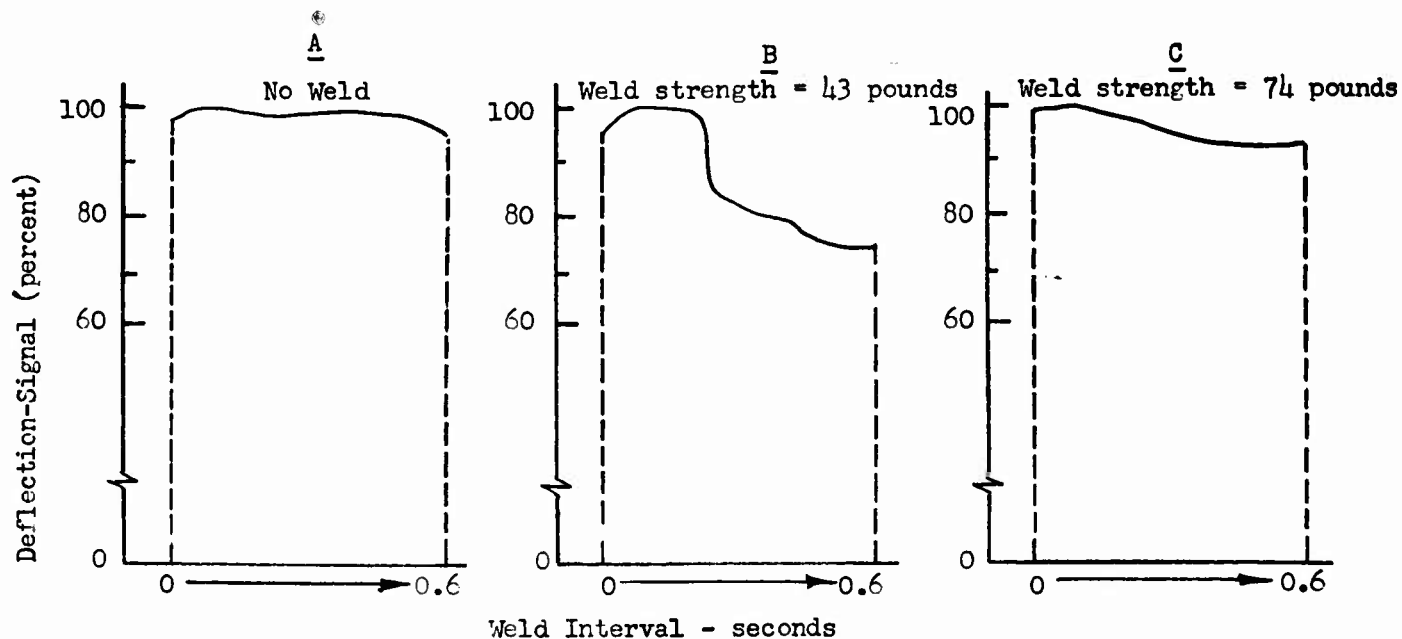
\* Private communication.

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Figure 4

## DEFLECTION-SIGNAL CURVES FOR 0.005-INCH Mo-0.5Ti

(Input Power = 1.2 'w; Clamping Force = 300 pounds)



After an initial "pre-coupling" period, specimen "B" apparently absorbed energy at a very rapid rate and formed a bond; the strength of the bond, however, was below the average for this material. Specimen "C", which exhibited one of the highest tensile-shear values obtained in this program, absorbed energy in a gradual manner.

Deflection-signal curves were also recorded for the five specimens of 0.005-inch Cb(D-31) discussed previously. All the curves were essentially the same as the one presented in Figure 5.

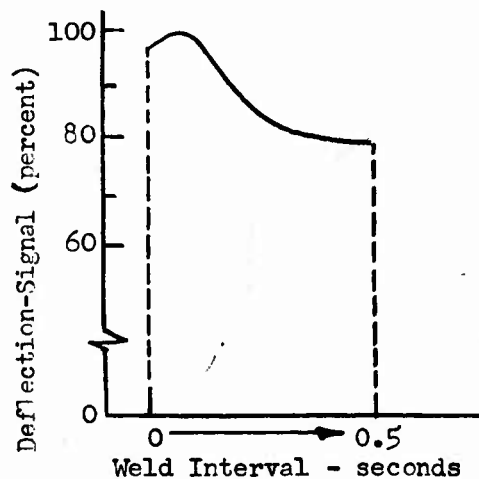
Figure 5

## 0.005-INCH Cb(D-31)

Welded at:

Input power: 750 watts  
 Clamping Force: 300 pounds  
 Weld Interval: 0.5 second

(Tensile strength = 40 pounds)



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The shape is similar to that of Figures 4C and 2A. The importance of power-force programming, and control of the weld time is clearly emphasized.

#### INSPECTION TECHNIQUES

For reasons discussed previously, several techniques for determining weld integrity were explored. The planar-sectioning method, is reliable but is too slow and expensive for evaluating welds in thin gages of the refractory metals. The use of a highly sensitive penetrant such as "Super Pentrex" was explored, but this procedure failed to provide the necessary information on weld integrity, because the discontinuities were internal and did not extend to the surface.

The effectiveness of ultrasonic inspection techniques is currently being investigated. Coupons of 0.005- and 0.010-inch Mo-0.5Ti were submitted to two outside firms for examination by ultrasonic methods. This work has not been completed.

The possibility of using an ultrasonic device, originally developed for evaluating exfoliation (corrosion along grain flaws) in aluminum alloys, for detecting cracks in specimens of the refractory metals is also being considered.

While normal X-ray radiography is useful for determining gross imperfections in ultrasonic welds, it is not a reliable means of detecting fine internal structure. Other X-ray techniques might be developed for this purpose but more complex procedures and, probably, more time would be required to carry out such inspections.

#### FUTURE WORK

Since the feasibility of welding various refractory metals has been demonstrated, (in this program as well as in independent work in our laboratories), the status of the work to date is being reviewed. Future work will be planned and scheduled on the basis thereof.

Very truly yours,

*C. R. Frownfelter*

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Senior Engineer-Staff Assistant

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