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**The Shear Strength of Soft-Soldered
Brass Joints as a Function of
Age and Temperature History**

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by

D. H. Liebenberg

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THE SHEAR STRENGTH OF SOFT-SOLDERED BRASS JOINTS AS A FUNCTION OF AGE AND TEMPERATURE HISTORY

by

D. H. Liebenberg

ABSTRACT

The ultimate shear strength of overlapped joints of 60 tin-40 lead solder on brass was measured under various conditions. The effect of age up to 330 days after soldering is reported. The effect on ultimate shear strength at room temperature of from 1 to 10 cycles to 77° and 20.5°K is measured. The ultimate shear strength at 77° and 20.5°K is measured for some samples, and some evidence is found for low temperature discontinuous yielding.

INTRODUCTION

As a part of the program to study metals properties at cryogenic temperatures, the ultimate shear strength (F_{su}) of soft-soldered brass joints has been measured as a function of age and temperature history. Soft-soldered joints are in common use on cryostats, and this study presents data pertinent to the design of such joints under shear stress. The room temperature value of F_{su} after aging and/or thermal cycling was measured on an Instron tensile testing machine. Additional tests used a cryogenically adapted Instron tensile testing machine developed at the Los Alamos Scientific Laboratory. The low temperature testing showed discontinuous yielding of these joints before breaking.

EXPERIMENTAL

The samples for the initial study were standardized to be brass bar stock nominally 1/4 in. thick and 1 in. wide X 3 in. long. Jigs were built to control both the area wetted by the soft solder and the thickness of the solder layer. Variations of the wetted area were always less than 5% of the total area. To maintain uniformity of the fillet of

solder at the joint edges, a measured amount of solder was used to make up each joint.

The area of the soldered joint was an overlap, 0.992 in. X 0.656 in., of the two brass blanks in the jig. Hence the area of solder was 0.651 in.². (See Fig. 1.) The surfaces were cleaned with trichloroethylene and soldered with 60 tin-40 lead solder taken from a single spool. Each blank was measured before making the joint, and the joint thickness was measured after the completed solder joint had returned to ambient temperature. The solder joint

Fig. 1. The assembled soft-solder joint.

thickness was measured by means of a micrometer. An average thickness of 0.0024 in. obtained.

Use was made of gripper blocks on the Instron machine that could be offset to accommodate the joint and permit the initial pull to be only in shear. The brass was thick enough that only small deformation occurred from breaking of the solder joint. Misalignment errors averaged about 0.0015 in. No extensometer or strain measurement was made since only the ultimate shear strength was under study.

A standard crosshead speed of 0.05 in./min was used. Some dependence of F_{su} on the crosshead speed was observed in preliminary tests and may be expected with a soft-solder joint. No attempt was made to study this dependence although an increase of about 10% in F_{su} occurred for a 10 times increase in speed. The constant crosshead speed provides a basis for comparing the results and represents a conservative approximation to breaking forces encountered experimentally, e.g., the liquid flashing in a closed container.

To provide some statistical analysis of the results, the samples were divided into groups of five for testing. The standard deviation, σ , is defined as

$$\sigma = \sqrt{\frac{\sum_i (x_i - \bar{x})^2}{N}}$$

for N samples each of which breaks at force x_i when the arithmetic average of the data set is $\bar{x}$. In practice σ was less than 10% of the value F_{su} with this sample size. The standard deviation for a normal distribution is defined as

$$p = 0.67\sigma$$

Within the small sample number of five, a Poisson distribution is obtained but is not very significant.

To investigate some sources of error, a correlation between the thickness of a solder joint and its ultimate strength was made. There was no correlation within the 38 selected samples showing large (± 0.001 in.) deviation from mean joint thickness.

Some dependence of the breaking force on the type of flux used was noted. The resin type of flux (Nokorode) was compared with an acid flux (Ruby fluid), and, though no striking difference was found, the apparent area of bond from Ruby fluid was found

to be greater upon examining the broken specimens. Hence, this solder flux was used predominantly.

A second part of the study involved measurements of ultimate shear strength at liquid nitrogen (77°K) and liquid hydrogen (20°K) temperatures. The samples were modified slightly for use in the Instron machine operated at cryogenic temperatures. A 1-in.-diameter hole was bored in the end of each brass sample, and the completed joint was mounted on the tensile test machine with 1 in. ground pin connectors. The offset joint was accommodated by design of the pins. After mounting, the joint was cooled to the working temperature; equilibrium was obtained during a 15-min, or longer, hold period; and the machine was run to break the sample. The cryogen was removed after the breaking; hence, good temperature equilibrium obtained during the sample stressing.

RESULTS

The room temperature ultimate shear strength of aged and thermally cycled samples is shown in Table I and Fig. 2. For the noncycled samples form-

TABLE I

ROOM TEMPERATURE BREAKING OF SOFT SOLDERED JOINTS

Time between Soldering and Breaking (days)	Thermal Cycles	F_{su} (psi)	Solder Flux*
4	0	4983 $\pm$ 240	R
16	0	5020 $\pm$ 130	N
25	1 LN ₂ Fast	4445 $\pm$ 250	R
25	0	4496 $\pm$ 238	R
78	10 LH ₂ Slow	3070 $\pm$ 206	R
36	10 LN ₂ Slow	3374 $\pm$ 129	N
53	1 LH ₂ Slow	3723 $\pm$ 52	R
53	0	3854 $\pm$ 243	R
35	10 LH ₂ Slow	3591 $\pm$ 183	N
35	0	3333 $\pm$ 114	N
53	10 LN ₂ Fast	3937 $\pm$ 298	R
49	0	3034 $\pm$ 200	R
49	10 LN ₂ Fast early	2906 $\pm$ 108	R
50	11 LN ₂ Slow	3150 $\pm$ 161	R
49	1 LH ₂	3058 $\pm$ 117	R
51	10 LH ₂	3041 $\pm$ 195	R
50	10 LN ₂ Fast late	3090 $\pm$ 180	R
330	0	3677 $\pm$ 80	R

*R acid flux

N resin flux

Fig. 2. Ultimate shear strength versus time after soldering. For uncycled control samples, $\cdot$ = acid flux, $\times$ = resin flux; and for temperature-cycled samples, $\circ$ = acid flux, and $\otimes$ = resin flux. These data were obtained at room temperature.

ing the control group, the decrease of strength to about $0.75 F_{su}$, where F_{su} is the initial ultimate shear strength, is shown to be about complete after 50 days. Data were obtained for times up to 330 days after soldering. The standard deviation errors are listed in the table but not plotted.

There is some indication that resin-flux soldered samples lose strength more rapidly than either the cycled or noncycled acid-flux soldered joints. Temperature cycling of the joints appears to further decrease F_{su} for acid-flux soldered joints by as much as 20% from the mean of the uncycled curve. However, one control group broken 49 days after soldering shows a low value of F_{su} within the standard deviation of the cycled group. As might be anticipated, there is no dependence on the temperature of cycling, or the fast and slow warmup rates, or the number of cycles within the range of present data. The fast warmup rate was about $2^\circ\text{K}/\text{sec}$, and the slow

rate was about $0.063^\circ\text{K}/\text{sec}$. In the one set of early or late cycled specimens broken within 50 days, no significant difference was noted. The early cycles were made within 5 days after soldering, and the late cycles were made on the other group 5 days before breaking.

The results for noncycled samples are in good agreement with earlier work reported by A. S. Medvedev.¹ In measurements carried out with tin-lead solders as used in the present study, the aging effect up to 40 days after soldering was given. A decrease in F_{su} of 0.76 was found by him, although the initial and final strengths are a little greater than those observed in this study. From the present data, the net decrease after 40 days is 0.73, so the agreement is quite good. The temperature cycling data are new and indicate an additional strength decrease of as much as 20%.

Measurements made at low temperature are inter-

Fig. 3. A Part of the force vs time relation obtained from a solder joint at 20.5°K. In particular, the discontinuity in force of about 50 lbs is shown.

esting because of the values of F_{su} determined and because of the discontinuous yielding observed. The samples show no significant change of F_{su} from the mean curve of uncycled samples broken at room temperature. Many fewer samples were used in this test. The departures in F_{su} for samples broken at 20.5°K were all less than the standard deviation of the control samples. For the sample broken at 77°K this was not the case, but it is not considered significant.

An example of the discontinuity apparently due to discontinuous yielding is shown in Fig. 3. Although some samples were broken without the discontinuity and accompanying noise, one sample was broken after several such jumps and many lesser noises. No such discontinuities were ever observed at room temperature, and the magnitude of the force discontinuity was less at 77°K than at 20.5°K.

No direct comparison with other data is available. One study has been performed on solder wire

samples — not soldered joints — down to liquid hydrogen temperatures.² Since their crosshead speeds were at least 20 times those used here, the comparison is extremely difficult, but the present data do not indicate the increase in strength reported by Christian and Watson at low temperatures. The present room temperature stresses are nearly equivalent to theirs, and the dependence on crosshead speed agrees with their reported measurements. While Christian and Watson observed a decrease in ductility, they did not report the discontinuous yielding found here. There are some difficulties, then, in using pure wire measurements to predict the behavior of a soldered joint.

The present investigation has found the decrease of ultimate shear strength with age up to about 50 days and a much weaker dependence on the temperature cycles of a soldered joint. The ultimate shear strength of 60 tin-40 lead soft-soldered brass joints was also measured at 77° and 20.5°K where no increase in F_{su} was found and where occurrences of discontinuous yielding were noted.

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2. J. L. Christian and J. F. Watson, Design News 18, 118 (Jan. 1963).

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