ABSTRACT. This paper presents the results of experimental work conducted on soldered and brazed joints formed between two coaxial steel cylinders (bushing and pin), and loaded by an axial push or pull force up to fracture, with a view to determining the shear strength of such joints.

Tests were planned and carried out to cover a wide range of parameters, namely a diameter range of 10 to 80 mm and a diameter to height ratio of joint of 2 to about 72.

Shear strength values obtained under push type tests are found to exceed those obtained under pull type tests by some 50%. Strength values are further shown to increase with higher values of diameter to height ratio of joint, also with smaller pin size. This trend is herein confirmed analytically.

Introduction

The determination of the ultimate strength in shear of soldered or brazed joints presents certain difficulties as the applied shear stress is almost invariably accompanied by normal stress either tensile or compressive depending on the conditions of test. For this reason shear tests for soldered or brazed joints have not yet been generally standardized, such tests being so far conducted on an arbitrary basis.*

On reviewing earlier literature on the subject, we find that Koch and Pöntz (Ref. 1) obtained the shear strength of brazed joints using shear specimens acted upon by a pull type load, Fig. 1. They proposed that their test would be adopted as a standard procedure for the determination of the shear strength of brazed joints. Russel and Wiesner used similar specimens in their investigations on

*The approach taken by the Brazing and Soldering Committee of the American Welding Society is presented in the document, AWS C3.2-63 Standard Method for Evaluating the Strength of Brazed Joints — Ed.
high temperature brazing alloys (Ref. 2).

Another version of the shear test, carried out by Colbus (Ref. 3), applies on the joint a push type force (in contradistinction to a pull type force). Fig. 2. Bollenrath and El-Sabbagh used similar specimens in their investigations on high temperature strength of brazed joints (Ref. 4).

It is evident that while the pull type test is accompanied by radial tensile stress, the push type test is associated with radial compressive stress. The present work is mainly concerned with the determination of the shear strength of soldered and brazed joints in both pull and push type tests under various conditions of geometrical parameters.

Experimental Procedure

Brazed and soldered joints were made between two concentric cylinders as shown in Fig. 3, particulars of materials used being as follows:

Base metal —
Steel St 37.11 (DIN 1611)

Brazing filler metal —
BAg-40 (40%Ag + 20%Cu + 20%Zn + 20%Cd)

Soldering filler metal —
"Standard" Solder: 60%Sn + 40%Pb

Soldering Temperature = 250 C

The gap width (i.e., radial clearance) between mating components (pin and bushing) was made 0.1 mm (0.004 in.) and kept constant throughout all tests, this gap thickness being the optimum value as established by Colbus (Ref. 3).

Coaxiality between pin and bushing was assured by first machining them with conical ends so as to remain coaxial in the ceramic base during soldering or brazing, Fig. 3. Specimens were cut thereafter along section AA thus leaving the joint height h required for the test. Brazing time (viz. duration after melting of brazing filler metal) was 30 seconds, heating up to brazing temperature being accomplished in an electrically heated muffle furnace for small specimens and in a gas-fired furnace for specimens of diameters above 20 mm.

After parting off to the required height h, the fillet f was adjusted to a radius of 0.5 mm (0.02 in.).

The finished joint was subjected to either a tensile force (pull type test), Fig. 3(a), or a compressive force (push type test), Fig. 3(b), up to fracture. The shear strength was obtained by dividing maximum load by the sheared area of soldered or brazed joint.

Test Results

Ultimate shear strength values obtained for brazed and soldered joints in pull and push type tests are reproduced in Table 1, 2 and 3. Test results show that shear strength values as determined in the push type test well exceed those furnished by the pull type test by some 56% for brazed joints (Table 2).

A closer insight into the behavior of brazed joints as influenced by the ratio of pin diameter, d, to height of joint, h, is given in Fig. 4. It can be readily seen that the shear strength increases with smaller pin diameter, d, also with higher values of d/h. This may be attributed to the more favorable conditions of brazing under such circumstances, viz. more homogeneous thermal influences at brazed surfaces.

Analytical Treatment

The brazing or soldering layer is considered so thin that the radial stress would be very nearly equal to the tangential stress, i.e., \( \sigma_r = \sigma_t \).

In the present analysis, the axial stress in the thin layer is neglected, so is also any thermal stress resulting from the brazing or soldering process. Radial and tangential...
stresses are assumed uniform along the whole axial extent of the brazing or soldering layer.

In the push type test, by way of example, the pin is subjected to an axial compressive stress:
\[ \sigma_z = \frac{4P}{\pi d^2} \]  
and a consequential lateral or radial strain given by:
\[ \varepsilon_r = \frac{4P}{\pi d^2} \frac{v}{E} \]  

The radial displacement of the outer surface of pin can then be obtained from the relation
\[ \text{Rad. disp.} = \varepsilon_r \frac{d}{2} = \left( \frac{2v}{E} \right) \frac{P}{d} \]  

Table 2 — Shear Strength Values Obtained for Soldered Joints

<table>
<thead>
<tr>
<th>Specimen</th>
<th>d, mm</th>
<th>d, mm</th>
<th>Solder area, mm²</th>
<th>Ult. shear strength, kN/mm²</th>
<th>ULt. shear strength, ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pull type test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>35</td>
<td>24</td>
<td>682</td>
<td>2.79</td>
<td>3.96</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>24</td>
<td>601</td>
<td>2.88</td>
<td>4.09</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>24</td>
<td>576</td>
<td>2.79</td>
<td>3.96</td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>24</td>
<td>451</td>
<td>3.02</td>
<td>4.29</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>10</td>
<td>212</td>
<td>2.85</td>
<td>4.05</td>
</tr>
<tr>
<td>6</td>
<td>35</td>
<td>10</td>
<td>202</td>
<td>2.98</td>
<td>4.23</td>
</tr>
<tr>
<td>7</td>
<td>35</td>
<td>10</td>
<td>185</td>
<td>2.89</td>
<td>4.10</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td></td>
<td></td>
<td>2.91</td>
<td>4.13</td>
</tr>
<tr>
<td>Push type test</td>
<td>6</td>
<td>10</td>
<td>162</td>
<td>3.01</td>
<td>4.27</td>
</tr>
</tbody>
</table>

Now the thin brazing or soldering layer, being considered as a thin-walled open cylinder with constraint around its external surface, will be subjected to the squeeze action resulting from the compression of the pin.

Assuming the radial displacement of pin to be equal to the radial squeeze of the brazing or soldering layer, we arrive at the equation:
\[ \frac{2v}{E} \frac{P}{d} = \frac{d}{2E} \left( \sigma_t - \nu \sigma_z \right) \]  

in which \( \sigma_t \) and \( \sigma_z \) denote tangential and axial stresses in brazing or soldering layer respectively.

The tangential (or radial) stress in the thin layer will be given approximately by:
\[ \sigma_r = \sigma_t = \frac{4P}{\pi d^2} \]  

The stress state for the brazing or soldering layer is shown in Fig. 5, from which it can be readily seen that:

Ultimate shear strength in the push type test
\[ \tau_B = \frac{P_{\text{max}}}{\pi d^2} \left( \frac{h^2}{4} + \frac{2v}{E'} \frac{h}{d} \right)^{1/3} \]  
or
\[ \tau_B = \frac{P_{\text{max}}}{\pi dh} \left[ 1 + \left( \frac{2v}{E'} \frac{h}{d} \right)^2 \right]^{1/3} \]  

It is evident from Eq. (6) that the shear strength of the material would be expected, in the push type test, to increase with:
(a) smaller size of pin d,
(b) higher value of the ratio d/h.

These theoretical predictions are confirmed by experimental results as shown in Fig. 4.

It is worthy to note that the shear strength obtained in this type of test depends on the geometrical parameters, which should be precisely specified in any standard form or test.

Should it be possible to greatly reduce or even eliminate the compression of the pin, radial and tangential stresses in the brazing or soldering layer would disappear, thus rendering a case of plane stress and plane strain (i.e., case of pure shear), in which \( T_B = \frac{P_{\text{max}}}{\pi dh} \). This can be approached at relatively high values of the joint diameter to height ratio d/h, Eq. (6).

**Summary and Conclusion**

Brazed and soldered joints made between cylindrical steel pins and co-axial steel rings were tested under two types of tests, viz., push and pull types, with a view to the determination of the ultimate shear strength of such joints.
Discussions

The *Welding Journal* invites critical discussions by peers on technical matters appearing in the Welding Research Supplement. A copy of the discussion will be mailed to the author for reply. Both discussions and reply will be printed together in these pages. Where conclusions and findings vary among different researchers, the reader will benefit from the information.
by P. A. Tichauer

The submerged arc weld in HSLA line pipe is examined by briefly reviewing the metallurgy of high-strength low-alloy steels and then considering how the welding process affects this metallurgy. Particular emphasis is given to the influence of thermo-mechanical processing and to the role of micro-alloy additions as they relate to strength, grain size and toughness. The metallurgy of the weld is contrasted to that of the base plate, and some recent investigations are reviewed. The influence of consumable selection is considered, and some recommendations for further study are made.

2. "Experience in the Development and Welding of Large-Diameter Pipes"  
by M. Civallero, C. Parrini and G. Salmoni

The production of X70 pipes up to 30 mm wall thickness with high base-material toughness has become necessary and possible today. In the choice of the most suitable type of steel, the mill and field weldability problems have been considered, as well as the weld-joint toughness requirements.

Of the experimental solutions, the best appears to be a control-rolled dispersoid steel, with extra-fine structure (mostly acicular type) with reduced pearlite and controlled inclusions. This steel, welded with the normal double-pass submerged arc techniques, allows one to achieve good toughness in the heat-affected zone, and to improve weldability compared to conventional steels. By further improving the type of flux on the basis of the theories developed, and by widening the knowledge of the effects of chemical composition (correlation between chemical composition, liquid-and-solid, austenite-to-ferrite transformation and final structures), it is believed possible to improve the low-temperature toughness up to the 10 kg/cm² level at temperatures down to -40 C, in wall thicknesses up to 30 mm.

3. "New Development in Weldability and Welding Technique for Arctic-Grade Line Pipe"  
by E. Miyoshi, Y. Ito, H. Iwanaga and T. Yamura

In this study, low-temperature burst tests were performed on 48-in. diameter x 1-in. thick x 8-ft long line-pipe specimens of a 1% Ni steel recently developed and produced by controlled rolling. Notches twice the size of the largest allowable defect in API Std. 1104 were incorporated in the longitudinal weld seam. Test data were assessed by a COD approach. Two heat inputs were used in welding the specimens. A special GMA welding technique was developed for the lower heat input. It was found that the lower heat input was the best method of improving the fracture toughness of the weld.

4. "Technology of Wires and Electrodes for Welding High-Strength Pipe"  
by J. Grosse-Wordemann

During the past few years, developments have led to steel grades with improved mechanical properties and reduced carbon content, compared to the previously known carbon-manganese grades. The new steels have improved weldability and API grades X60, X65 and X70 are already in use. The development of X80 is close to completion. This paper reviews the latest technology in developing suitable filler metals for welding these high-strength line-pipe steels.

5. "Preliminary Evaluation of Laser Welding of X-80 Arctic Pipeline Steel"  
by E. M. Breinan and C. M. Banas

Single- and dual-pass laser welds were made in an alloy steel currently being evaluated for potential Arctic gas pipeline applications. The laser welds exhibited excellent overall mechanical properties and a Charpy shelf energy greater than 264 ft-lb, which is substantially above that of the base material. Dual-pass welds exhibited a ductile-to-brittle transition temperature below -60 F. Increased shelf energy was attributed to a reduction in the visible inclusion content of the fusion zone while transition temperature was shown to be strongly dependent upon fusion-zone grain size.

Paper (1) was prepared for the Subcommittee on Line-Pipe Steels of the Weldability (Metallurgical) Committee of the Welding Research Council. The other four papers were presented at a session sponsored by this subcommittee during the 1974 AWS Annual Meeting.

The price of WRC Bulletin 201 is $8.00 per copy. Orders should be sent with payment to the Welding Research Council, 345 East 47th St., New York, N.Y. 10017.