Interface Properties in Friction Welding: A Technical Note

The influences of HAZ hardness characteristics on the properties of a dissimilar metal tensile specimen are analyzed

BY S. D. BHOLE

ABSTRACT. This note discusses the microstructure and hardness in the heat-affected zone of a friction weld between a mild steel bar and a high-strength low-alloy (HSLA) steel plate. The torsional shear and frictional heat generated by welding leads to phase transformations resulting in fine bainitic or martensitic microstructures. A hardness profile across the weld shows a sharp peak in hardness in the vicinity of the weld interface that could affect the properties of the weld. This should be considered when friction welding is used to produce tensile test specimens for through-thickness testing.

Introduction

Friction welding is a special form of forge welding in which the energy required to produce a weld is acquired from the frictional heat generated at the rubbing surfaces under high pressure. The two surfaces are heated close to the melting temperature, making the adjacent material plastic. The two surfaces are forged together under pressure to achieve an upset joint. A major advantage of the process is that sound welds may be produced in many dissimilar metal combinations not considered weldable by conventional processes (Refs. 1–3).

In general, friction welding produces very limited and narrow heat-affected zone (HAZ) regions. The properties of the HAZ, especially strength and hardness, are of interest since they affect the overall properties of the weldment structure. Because of its narrow HAZ, friction welding has been used to weld extension pieces to thick strip or plate samples to enable machining of tensile test specimens in the through-thickness (z-) direction. The through-thickness properties, such as strength and ductility, are important for applications of steel strip and plate for thick-walled pressure vessels, linepipe, storage tanks and ship hulls. In such applications, cracking can occur during welding of strip or plate with low transverse ductility with the cracks following the line of sulfide inclusion stringers; this phenomenon is referred to as lamellar tearing (Refs. 4, 5).

The ASTM standard on tensile testing of metallic materials (Ref. 6) does not mention through-thickness tests, and thus, the procedures and practices for it are left to the discretion of the testers and their clients.

It has been observed that in controlled rolled HSLA steels subjected to flash weld-

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KEY WORDS

Friction Welding
HAZ Properties
Heat-Affected Zone
HSLA Steel
Hardness
Microstructure
Tensile Testing
Dissimilar Welds
Hardness Profile
Weld Interface

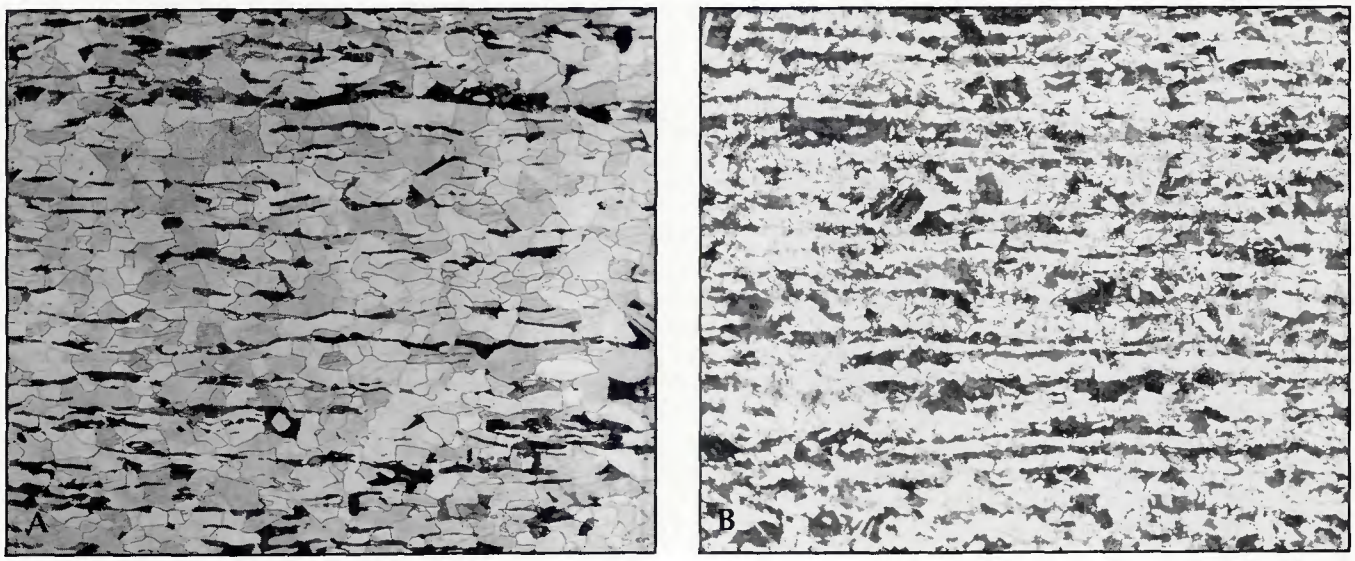

Fig. 1—Microstructures of as-received steels. A—mild steel bar (magnification 100×, nital etch); B—HSLA steel plate (magnification 200×, nital etch).

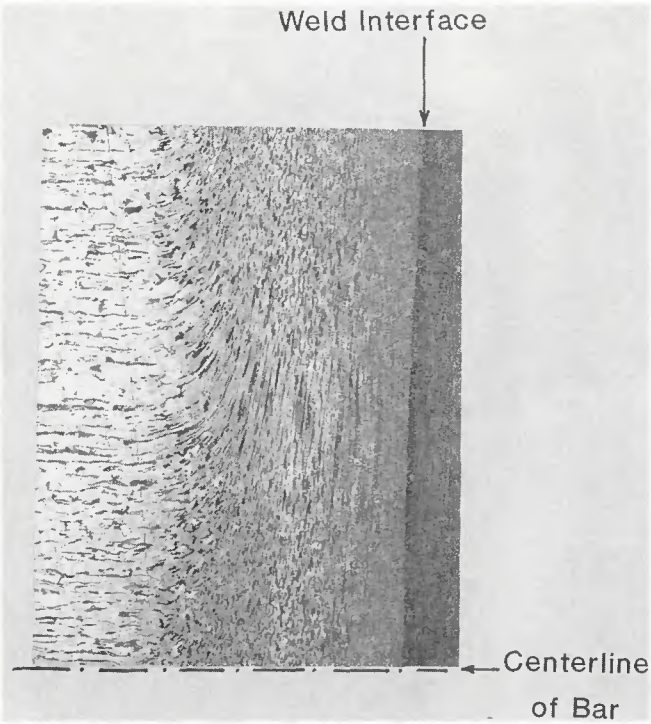

Fig. 2—Microstructure of rotating mild steel bar at weld interface (magnification 100X, nital etch).

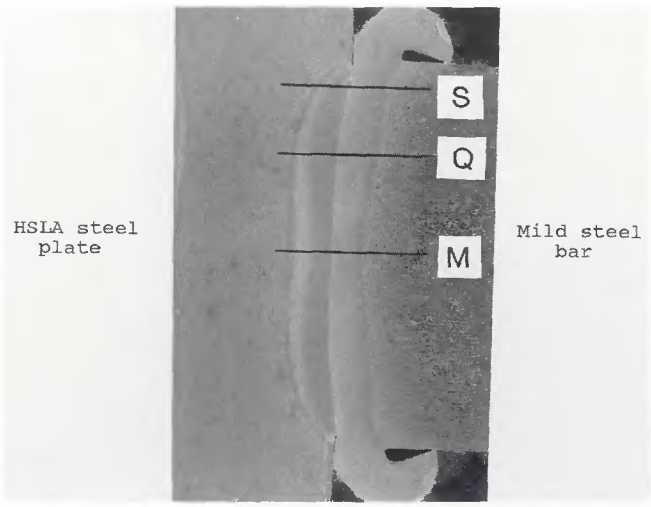

Fig. 3—Macrosection of friction weld showing HAZ shape and flash and location of hardness traverses; M = midsection; Q = quarter section; S = near surface (magnification 4X,. nital etch).

ing, which is similar to friction welding, the weld thermal cycle causes a softened HAZ where the tensile failure occurs at a lower strength level than that of the original base plate (Ref. 7). The same researchers showed that the softened zone became smaller with larger specimens and gave values of strength closer to that of the base plate. Other researchers (Ref. 8) observed that the friction weld interface in an austenitic stainless steel showed a hardness peak with a drop in hardness in the HAZ. It is expected that the change in microstructure and strength will also affect the ductility values.

The present work was undertaken to evaluate the properties of the HAZ of a friction weld between a mild steel bar and a high-strength low-alloy (HSLA) steel plate that was fabricated to obtain tensile test specimens in the through thickness (z-) direction in the HSLA plate.

Table 1—Chemical Analyses of Steels Used (wt-%)

Element	Steel: Mild Steel	Steel: HSLA
C	0.19	0.24
Mn	0.79	1.42
P	0.010	0.013
S	0.012	0.005
Si	0.03	0.22
Cu	0.01	0.32
Ni	0.02	0.33
Cr	0.04	0.12
Mo	0.01	0.068
Al	–	0.029
N	–	0.010
Nb	–	0.050

Experimental Procedures

The materials for the friction welding operation were a mild steel bar of 19-mm (0.75-in.) diameter and an HSLA steel plate of 9-mm (0.35 in.) thickness. The chemical analyses of the above steels are given in Table 1 and their microstructures are shown in Fig. 1.

Results

Microstructure

The microstructure at the weld interface shows range and variety. The rotating mild steel bar at the interface (Fig. 2) exhibits a microstructure of a thin layer of highly deformed and refined grains. The general shape of the HAZ (Fig. 3) is that of a wedge shape toward the center with a noticeable flash at the surface. This indicates that the welding conditions were a combination of low speed and high pressure (Ref. 9).

In the HAZ on either side of the interface, the microstructure shows a very fine structure of bainite or low carbon martensite—Fig. 4. Further away from the interface into the plate, the structure is the ferrite-pearlite type of the base plate but with a finer grain size.

Hardness

The hardness values are given in Fig. 5 for measurements at the midsection, quarter section and near-surface. Distance along the sections is measured starting at the weld interface and moving away into either the bar or the plate. The average hardness of the HSLA plate was HV 199 and the average hardness of the mild steel bar was HV 185.

The hardness showed a sharp rise on the HSLA side of the interface to the range of HV 515 to 546. The region of increased hardness extended to a maximum of about 2.25 mm (0.09 in.) across the interface. This region was smaller for the near-surface hardness profile.

Discussion

From the results of the hardness determinations and the microstructural examination, it is evident that the sharp increase in hardness is due to the formation of bainitic or martensitic microstructures in the HAZ. The lower peak values of hardness near the surface relative to the midsection can be explained on the basis that the near-surface peak temperatures will be relatively lower, resulting in lower hardness microstructures.

The implications of the higher hardness (*i.e.*, strength) in the HAZ depends on the application for which the friction weld is used. For evaluating the through-thickness (or z-direction) mechanical properties of a

Fig. 4 — Fine microstructure in HAZ of HSLA steel plate (magnification 400X, nital etch).

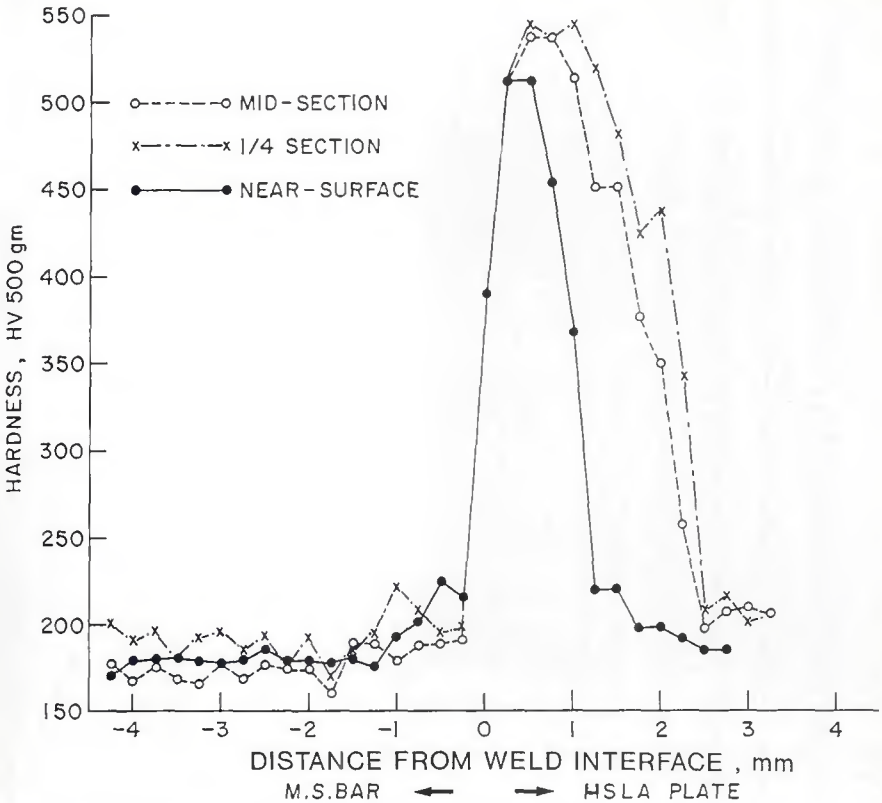

Fig. 5 — Hardness profiles at different locations in friction weld.

plate, a mild steel bar can be friction welded on both sides of the plate surface and a test specimen machined from this with the gauge length located in the plate section. In such a situation, there will be some influence of the weld HAZ on the plate properties. Taking the case of the weld in this report for a plate thickness of 9 mm, the higher hardness of the HAZ extends about 2 mm (0.08 in.) into the plate from either side, leaving about (9 − 2 × 2 =) 5 mm (0.2 in.) unaffected in the central region. Thus, the differences in the hardness of the welded HSLA plate through its cross-section could have a bearing on the results of the tensile test.

Hence, it is important to know the effect of the friction weld operation on the base plate HAZ.

Conclusion

A friction weld was carried out between a mild steel bar and an HSLA steel plate. The hardness survey revealed significantly higher hardness in the HAZ of the HSLA steel plate. This was consistent with the microstructure produced due to the thermal cycle. The predominant structure was bainite or low-carbon martensite.

Results obtained from the use of friction welds to produce tensile test specimens to evaluate through-thickness (z-direction) properties of plate must be qualified by a knowledge of the HAZ properties and the HAZ size. These can dramatically influence base plate properties if this size is appreciable with respect to the plate thickness.

Acknowledgments

The friction welded samples were supplied by IPSCO, Inc., Regina, Canada.

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