IMPACT TENSILE STRENGTH OF FRICTION WELDED JOINTS BETWEEN 6061 Al ALLOY AND S45C STEEL

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ABSTRACT The impact tensile strength of friction welded joints between 6061 Al alloy and S45C steel is evaluated with the split Hopkinson bar technique. Round tension specimens machined from the friction welded joints are used. It is shown that the impact tensile strength of the friction welded joints is slightly lower than the corresponding static strength. Macroscopic observations reveal that there is significant difference in the manner of fracture of the friction welded joints in the static and impact tensile tests. The decrease in tensile strength of the friction welded joints with increasing loading rate may be attributed to the presence of brittle intermetallic phases formed at the joint interface during the friction welding operation.

Keywords: *Impact tensile strength, Aluminum/steel friction-welded joint, Hopkinson bar*

1. INTRODUCTION

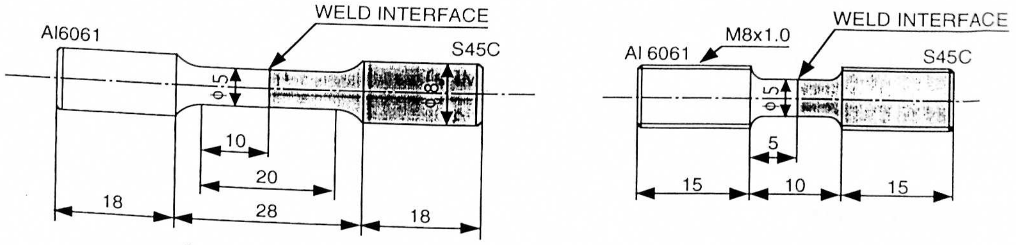
In the last decade, friction welding has come to assume a position of importance in the fabrication industry. The advantages of the process are, among others, high reproducibility, short production time and low energy input. Friction welding has made possible welding of dissimilar metals such as titanium alloys, aluminum alloys and new materials to which the conventional welding techniques cannot be applied. So far, the mechanical performance of various friction welded joints [e.g. 1-3] has been evaluated primarily under quasi-static loading. A precise knowledge of the mechanical behavior of the friction welded joints under impact loading is required for their further wide applications in fabrication industry. However, the impact strength of the friction welded joints has not been well examined owing to the experimental difficulties associated with impact testing.

The purpose of the present work is to determine the impact tensile strength of friction welded joints between 6061 Al alloy and S45C steel. The impact tension tests on the friction welded joints were conducted using the split Hopkinson bar apparatus. Round tension specimens machined from the friction welded joints were used in the static and impact tests. The friction welding parameters (rotating speed, friction pressure and time, forging pressure and time) were maintained constant. The test results indicate that the tensile strength of the friction welded joints decreases slightly with increasing loading rate up to 10^6 MPa/s. Visual observations reveal that the static tensile fracture takes place near the weld interface on the 6061 Al alloy side of the specimens, while the impact tensile fracture occurs at the weld interface of the specimens. The micro-indentation hardness tests show that the effect of heat generated by the welding operation on the mechanical properties of the base metals (or 6061 Al alloy and S45C steel) is restricted within nearly 10 mm from the weld interface under a given friction welding condition. The decrease in tensile strength of the friction welded joints with increasing loading rate may be due to the presence of brittle intermetallic compounds formed at the joint interface region.

2. EXPERIMENTAL DETAILS

2.1 Preparation of friction welded joints

The geometrical details of the static and impact tension specimens are shown in Fig. 1. Tension specimens were machined from 30-mm diameter 6061Al/S45C steel friction welded bars. The chemical composition and nominal tensile properties of the base metals are given in Tables 1 and 2. Friction welding was carried out using a brake type friction welding machine (Nitto Seiki, FF-50II-C). The friction welding parameters controlled by the machine are schematically shown in Fig.2.



static tension specimen

impact tension specimen

Fig. 1 Dimensions of static and impact tension specimens from friction welded joints

Table 1 Chemical composition of base metals

Material	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al	C	P	S	Ni
6061-T6 Al	0.69	0.2	0.38	0.02	1.0	0.08	0.01	0.02	Bal.	–	–	–	–
S45C	0.19	Bal.	0.007	0.64	–	0.011	–	–	–	0.45	0.02	0.015	0.005

Table 2 Nominal tensile properties of base metals

Material	Yield strength σ_Y (MPa)	Tensile strength σ_B (MPa)	Elongation δ (%)
6061-T6 Al	283	324	21
S45C	422	770	23

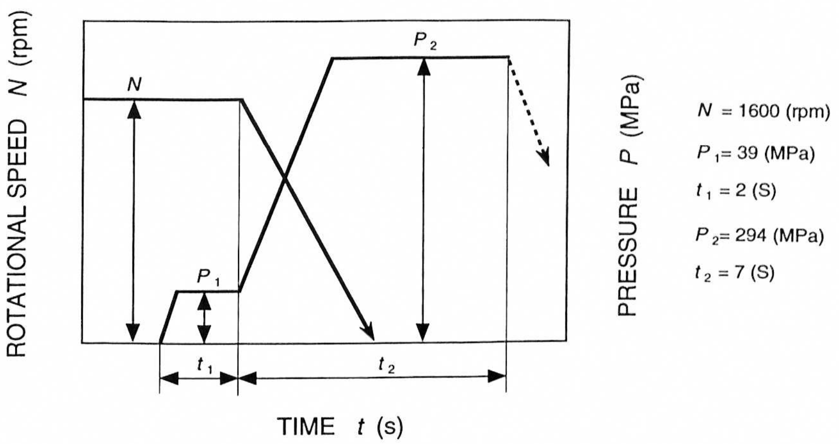


Fig. 2 Schematic diagram showing friction welding process

2.2 Tensile Hopkinson bar apparatus

Figure 3 indicates a schematic drawing of the tensile split Hopkinson bar apparatus [4] used in the present tests. The apparatus consists principally of a striker bar, a gun barrel, two Hopkinson bars (bar No.1 and bar No.2) and associated recording system. The apparatus is described only briefly here; details are reported elsewhere[5]. The striker bar is a 350-mm long carbon tool steel rod with a 16-mm diameter. The Hopkinson bars supported on V-shaped blocks are made of 16-mm diameter bearing steel rods. The impact tension specimen with threaded ends is attached to the two Hopkinson bars(see, the inset in Fig. 3). After the specimen has been screwed into one of the two Hopkinson bars, a split collar is placed over the specimen, and the specimen is then screwed in until the Hopkinson bars fit tightly against the collar. The split collar has the same outer diameter of 16 mm, and an inner diameter of 8 mm just to clear the specimen.

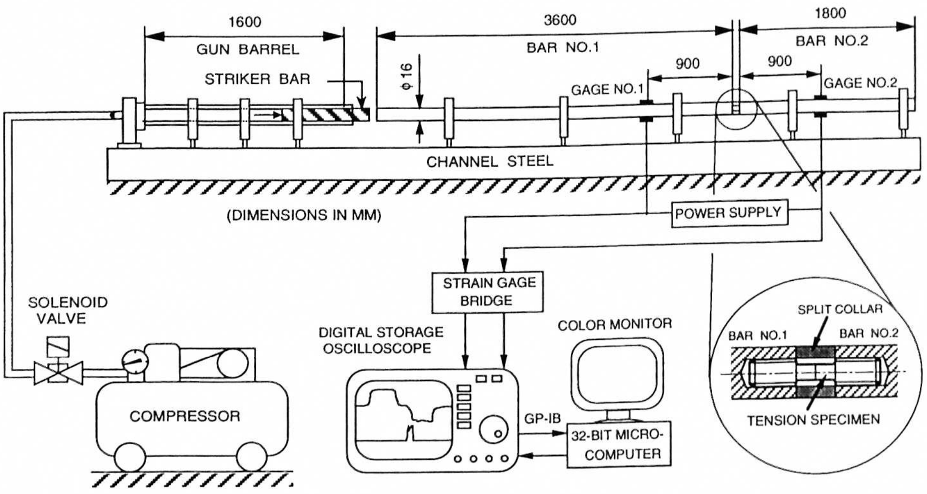


Fig. 3 Tensile split Hopkinson bar apparatus and associated recording system

2.3 Data reduction

By applying the one-dimensional theory of elastic wave propagation, the average strain ε, an stress σ along the gage length of the specimen are determined from the Hopkinson bar test records a

$$\varepsilon(t) = \left(\frac{c_0}{L}\right)\int_0^{t}\left[\varepsilon_i(t') - \varepsilon_r(t') - \varepsilon_t(t')\right]\mathrm{d}t'$$

$$\sigma(t) = \left(\frac{AE}{A_s}\right)\varepsilon_t(t)$$

Here A, E and c_0 are the cross-sectional area, Young's modulus, and the elastic longitudinal wa velocity of the Hopkinson bars; L and A_s are the initial gage length, and the cross-sectional area of the specimen; ε_i, ε_r and ε_t are incident, reflected and transmitted strain pulses; and t is the time from the start of the pulse. Equations (1) and (2) provide the average nominal strain and stress in the specime as a function of time t., respectively. Eliminating time t provides the nominal (or engineering stress-strain curve for the specimen.

3. TEST RESULTS AND DISCUSSION

3.1 Static tension tests

Static tension tests at low and intermediate rates of loading were performed on an Instron testing machine (Instron, Model 4505) at two different crosshead speeds of 2 and 100 mm/min, respectively Figure 4 shows typical stress-time history obtained at the low crosshead speed of 2mm/min. The static tensile strength of the joint specimen is determined from the peak value which can be identified as fracture initiation.

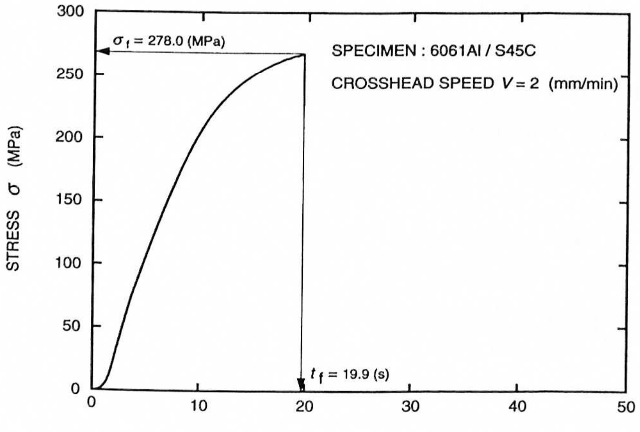
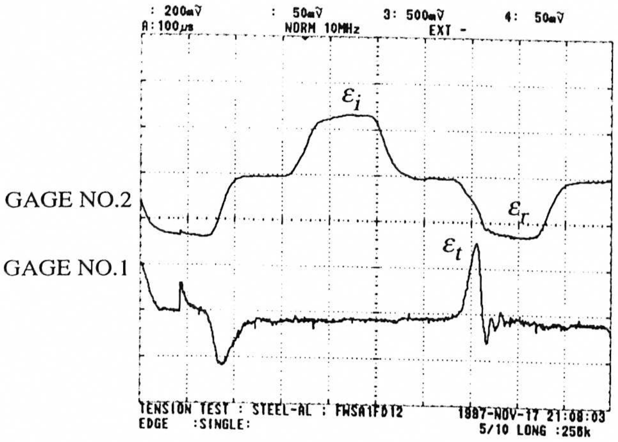


Fig. 4 Tensile stress-time history for joint specimen from Instron testing machine

3.2 Impact tension tests

A number of impact tension tests were conducted using the split Hopkinson bar apparatus a room temperature. Figure 5 presents a set of typical strain-gage records from the tensile Hopkinson bar test on the joint specimen. The upper trace from strain gage No.2 gives the incident and reflecte strain pulses; the lower trace from strain gage No. 1 gives the strain pulse transmitted through the specimen. Figure 6 indicates the resulting tensile stress-time history for the joint specimen, deduced from the data in Fig. 5. As in the static tensile tests, the impact tensile strength is determined from the maximum value of the tensile stress-time history. In an effort to examine the effect of loading rate (or stress rate) on the joint tensile strength, the static and impact strength data are replotted as a function of loading rate in Fig. 7. The loading rate is defined as the tensile strength σ_f divided by the time to fracture t_f. It is seen that there is considerable scatter in the static and dynamic tensile strength data, but there is no large variation in the tensile strength data for the joint specimens taken from the central and peripheral regions in the friction welded joints. It should be noted that the tensile strength decreases slightly with increasing loading rate. As pointed out in [6], the decrease in tensile strength may be due to the presence of brittle intermetallic films (e.g. of the type Fe_2Al_3 and Fe_2Al_5) formed at the joint interface.



Sweep rate : 100 μs/div.
Vertical sensitivity
upper trace: 702με/div.
lower trace: 70με/div.

Fig. 5 Typical strain-gage records from tensile split Hopkinson bar test on joint specimen

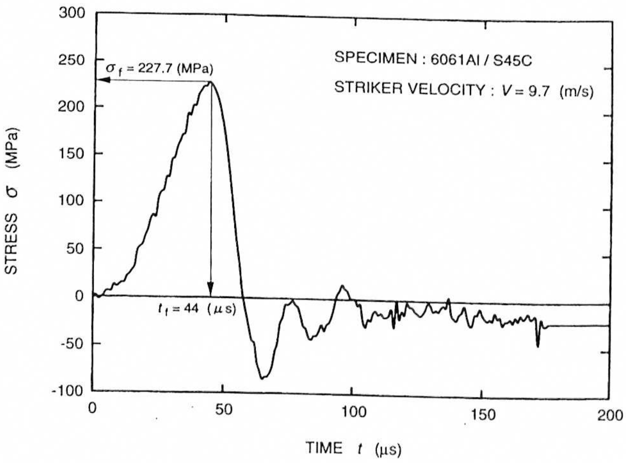


Fig. 6 Tensile stress-time history for joint specimen from Hopkinson bar test

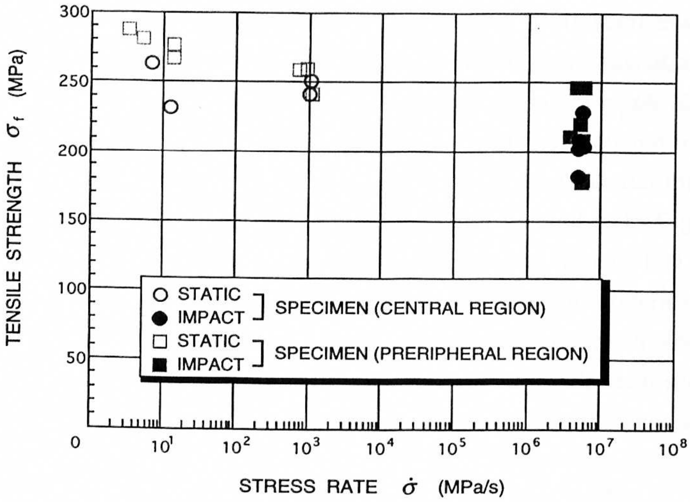


Fig. 7 Effect of loading rate on tensile strength of friction welded joints

4. CONCLUSIONS

The split Hopkinson bar technique has been successfully applied to the accurate evaluation of the impact tensile strength of the 6061Al/S45C steel friction welded joints. From the present experimental investigation, the following conclusions can be made:

(1) The tensile strength of the 6061Al/S45C steel friction welded joints at loading rates of the order of 10^6 MPa/s can be determined using the split Hopkinson bar technique.

(2) The tensile strength of the 6061Al/S45C steel friction welded joints decreases slightly with increasing loading rate.

(3) There is significant difference in the manner of fracture of the friction welded joints at low and high rates of loading, but there is no large variation in the tensile strength data for the joint specimens taken from the central and peripheral regions in the friction welded joints.

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