High-Impact Strength Brazed Joints in Steels

Impact strength is increased significantly when a columnar structure unites the base metals

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ABSTRACT. High-impact strength brazed joints in steels were developed by utilizing a method of dissolution and deposit of base metal. Charpy U-notch (CUN) impact strength of similar carbon steel joints brazed with Cu filler metal was found to be only 2.9 J/cm^2 (1.7 ft-lb) at room temperature, regardless of carbon content of the base metal, the joint clearance or the holding time. In the case of a dissimilar carbon steel joint, however, dissolution and deposit of base metal takes place, and as a result, both base metals are united with a columnar structure of the deposited Fe/9–12 Cu/1–2 C alloy. This is a valid way of strengthening brazed joints, *e.g.*, the CUN impact strength of a low-carbon steel (0.17 C)/high-carbon steel (1.04 C) joint was increased remarkably from 2.9 J/cm^2 (1.7 ft-lb) to 27.2 J/cm^2 (16.0 ft-lb).

Even in a similar low-carbon steel joint, when using a special proprietary filler metal of a high-carbon steel foil plated with 10-μm (0.0004-in.) thick Cu on both sides, both base metals are also united by the columnar phase, which is initiated by the foil plating. As a result of this uniting, the CUN impact strength of the joint was increased to 89.4 J/cm^2 (52.8 ft-lb). Moreover, when one side of a low-carbon steel was carburized to an effective case depth of 0.2 mm (0.008 in.) prior to brazing, the columnar phase developed from the carburized low-carbon steel side, uniting both base metals. Consequently, the CUN impact strength of the joint was 89.2 J/cm^2 (52.6 ft-lb).

Introduction

Brazed joints are generally weak to impact loads. This results in a low reliability of the mechanical properties of the joints. Peaslee, *et al.* (Ref. 1), showed that at room temperture the Charpy keyhole impact strength in a joint of high-temperature S-590 alloy steel brazed with Cu filler metal was only ~3.4 J/cm^2 (2.0 ft-lb).

In brazing dissimilar carbon steels with Cu filler metal, the low-carbon steel dissolves in molten Cu. Simultaneously, as the temperature is kept constant, the dissolved low-carbon iron forms a columnar Fe/Cu/C alloy deposit from the high carbon steel. This phenomenon has been named "dissolution and deposit of base metal" (Ref. 2). When both base metals were united by the columnar formation, the shear strength of the joint was increased markedly from ~300 MPa (43.5 ksi) to 500–600 MPa (72.5–87.0 ksi) (Refs. 3, 4).

The aim of the research described here was to greatly increase the impact strength of carbon steel joints brazed with Cu filler metal by utilizing the dissolution and deposit of base metal phenomenon, which unites both base metals with the columnar phase.

Experimental Procedure

Tests were conducted on both similar and dissimilar joints which combined 10 × 10 × 27.5-mm (0.4 × 0.4 × 1.1-in.) square rods of low-carbon steel (0.17 C) and high-carbon steel (1.04 C). The joints were then subjected to polishing and cleaning with acetone. Also, gas carburizing to an effective depth of 0.2 mm (0.008 in.) was performed on the low-carbon steel.

Pure Cu (99.99%) was used as the filler metal, and tungsten (W) wires having appropriate diameters were adapted for use as joint spacers.

A braze specimen assembly is shown in Fig. 1. One side of a square butt joint was chamfered in order to make a pool of molten filler metal during heating. A specially developed filler metal (Ref. 5)

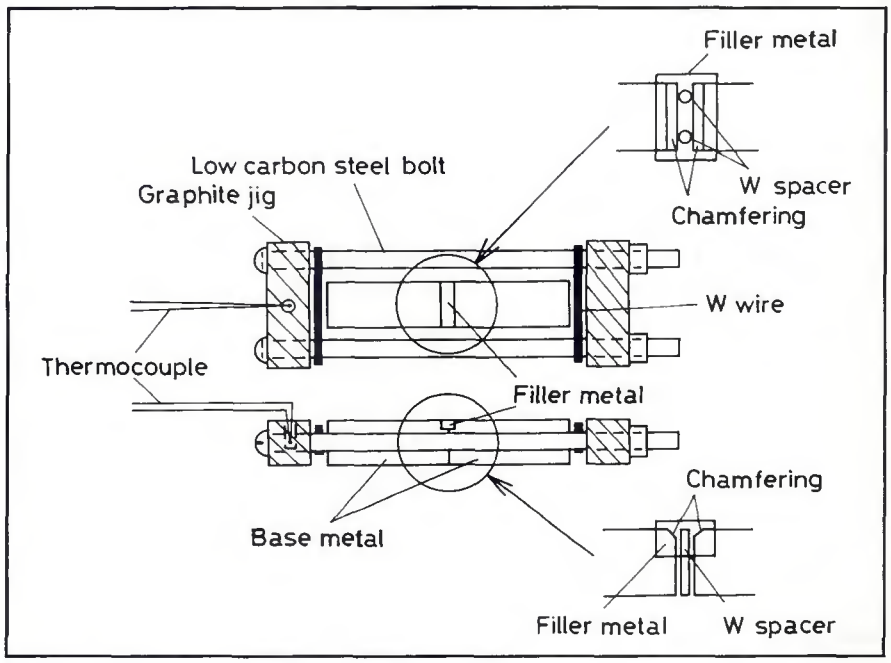

Fig. 1—Assembly of braze impact specimen

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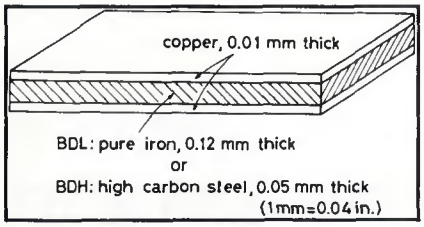

Fig. 2 — Schematic of special proprietary filler metal

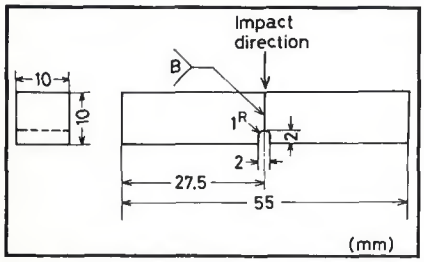

Fig. 4 — Shape and size of braze impact specimen

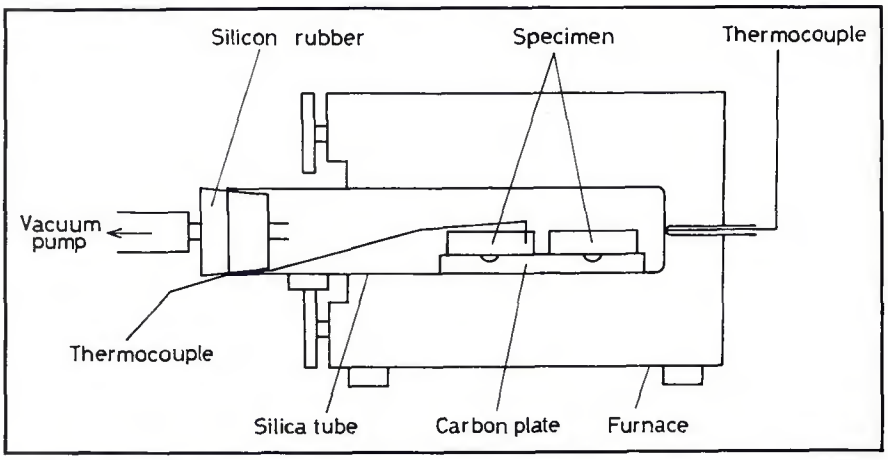

Fig. 3 — Brazing method

was also used. It consisted of pure iron (99.9 Fe) or high-carbon steel (1.0 C) foil electroplated with Cu of 10-μm (0.0004-in.) thickness on both sides (Fig. 2), using a Cu cyanide bath and then a Cu sulfate bath. The assemblies were placed on a graphite plate that had two U-shaped grooves (Fig. 3), and then the silica tube container was evacuated at 0.133 Pa (10^{-3} torr) and inserted into a furnace (Ref. 3).

After the brazing operation, the surfaces of each specimen were smoothed with a surface grinder, and a U-notch was machined in the center of the chamfered side — Fig. 4. Prior to machining, the high-carbon steel was annealed at 820°C (1508°F) for 40 min in an argon atmosphere to reduce its hardness for machining purposes. The hardness dropped from RC 38 to RC 16.

Impact tests were carried out at room temperature with a 294.2 J (217 ft-lb) Charpy impact tester. In order to make metallographic examinations, some of the specimens were sectioned perpendicular to the brazed surface and polished. The etchant used was 2% nital.

Results and Discussion

Impact Strength of Brazed Joints

Figure 5 illustrates the effect of holding time on the CUN impact strength of carbon steel joints with a 35-μm (0.0014-in.) joint clearance. The CUN impact strength of the joints with similar carbon steel was extremely low (approximately 2.9 J/cm^2/1.7 ft-lb), regardless of the carbon content of the steel or the holding time. The reason for this was that with the similar joints there was no distinctive characteristic microstructure at the braze

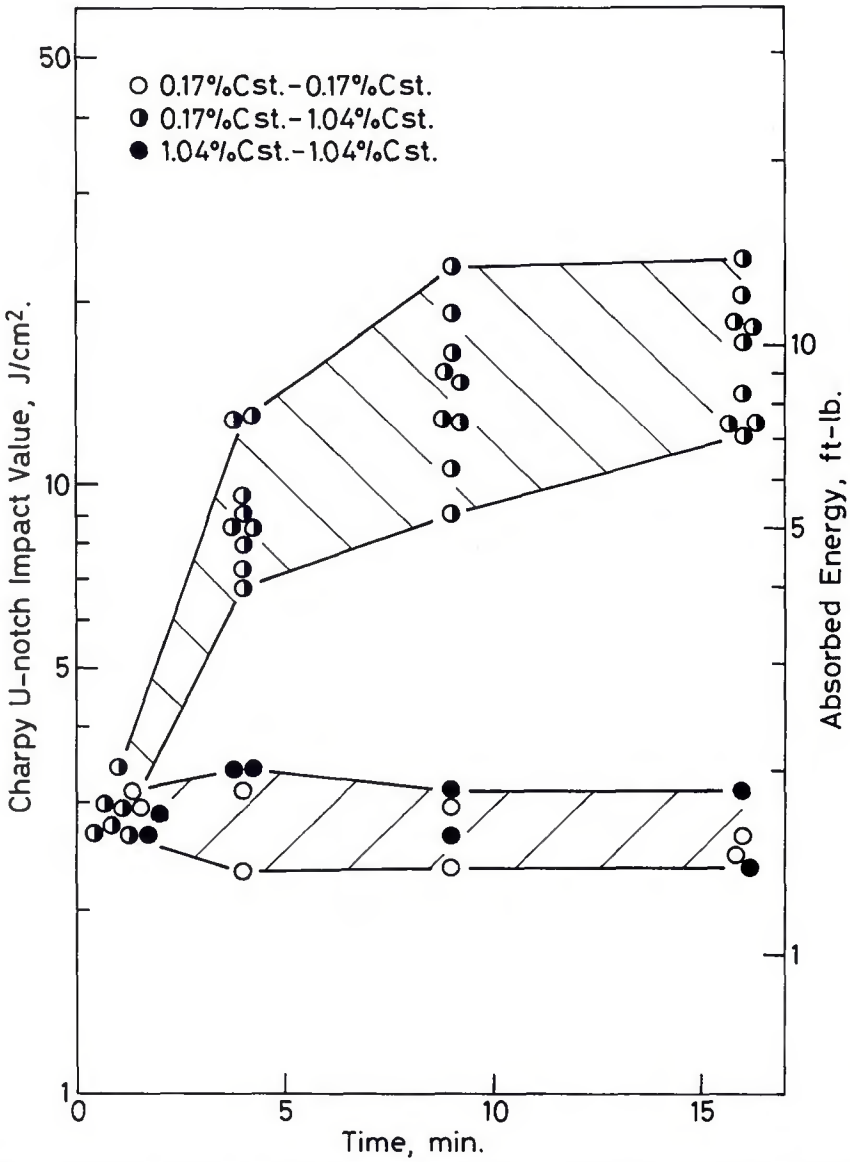

Fig. 5 — Effect of holding time on CUN impact strength in similar and dissimilar carbon steel joints at a joint clearance of 35 μm (0.0014 in.), brazed at 1125°C (2057°F)

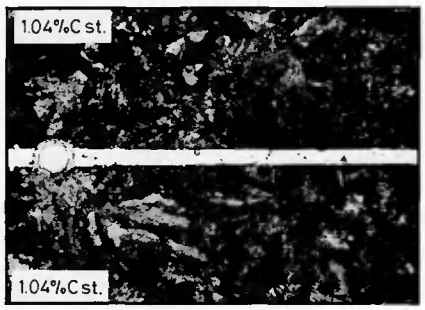

Fig. 6 — Microstructure of similar low- and high-carbon steel joints at 35 μm (0.0014 in.), brazed at 1125°C (2057°F) for 9 min (200X)

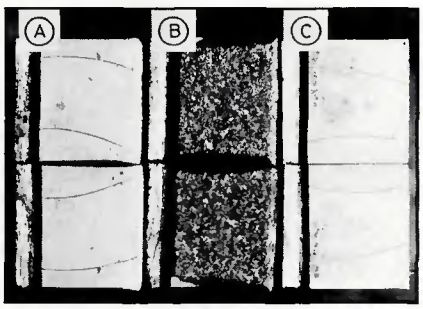

Fig. 7 — Appearance of fracture surfaces. A — Similar low-carbon steel joint; B — Dissimilar joint; C — Similar high-carbon steel joint. Streaks on similar joints are tungsten (W) wires of 35-μm (0.0014-in.) diameter

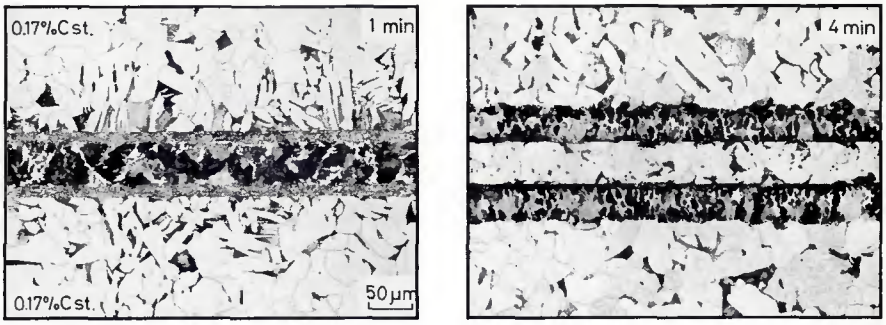

Fig. 9 — Microstructure of the similar low-carbon steel joint, brazed with the special filler metal (BDH) at 1125°C (2057°F) for 1 and 4 min (200X)

interfaces (Fig. 6), and the destruction of the joint always occurred in the Cu layer — Fig. 7.

In the case of the dissimilar carbon steel joint, the CUN impact strength increased markedly from 2.9 J/cm^2 (1.7 ft-lb) to 16.5 J/cm^2 (9.7 ft-lb) as the holding time increased — Fig. 5. This was the result of uniting both base metals with the columnar phase, which grew from the high-carbon steel to the low-carbon steel — Fig. 8. Because the columnar phase consisted of Fe/9-12 Cu/1-2 C, the joint fractured in the base metals instead of the Cu layer — Fig. 7. The degree of increase in impact strength induced by uniting was more remarkable for the narrow joint clearance, *e.g.*, the CUN impact strength of a dissimilar joint with no spacer (press fit) achieved 27.2 J/cm^2 (16.0 ft-lb).

Use of Special Filler Metal

Even in similar carbon steel joints, it becomes possible to utilize dissolution and deposit of base metal when using the proprietary filler metal — Fig. 2. Here, the high-carbon type special filler metal (BDH) and the low-carbon type (BDL) are used for similar low- and high-carbon steel joints, respectively. Since the dissolution and deposit of base metal takes place between the base metals and both sides of the foil, both base metals are united in the columnar phase through the foil — Figs. 9, 10. In addition, the foil is decarburized (Fig. 9) or carburized (Fig. 10) as a result of the diffusion of carbon through the columnar phase.

By using the special filler metal, the CUN impact strength of the similar low-carbon steel joint was increased remarkably to 89.4 J/cm^2 (52.8 ft-lb), as illustrated in Fig. 11, whereas the similar high-carbon steel joint increased slightly to 6.1 J/cm^2 (3.6 ft-lb). This great difference in impact strength could be associated with the toughness of the base metals. As is generally accepted, the addition of carbon to ferritic metal causes the toughness to decrease, *e.g.*, the CUN impact strengths of all-base-metal specimens were 267.1 J/cm^2 (157.6 ft-lb) for low-carbon steel in the as-brazed condition and 39.1 J/cm^2 (23.1 ft-lb) for high-carbon steel in the as-annealed condition.

Thus, it can be concluded that the impact strengths of the brazed joints that united both base metals with the columnar phase through the foil are significantly affected by the toughness of the base metals. This characteristic could be applicable to dissimilar carbon steel joints that had both base metals united by the columnar phase. The joints fractured primarily in the high-carbon steel, which has low toughness. This was because the CUN impact strength of the joint with no spacer did not exceed 27.1 J/cm^2 (16.0 ft-lb). As seen in Fig. 11, the CUN impact

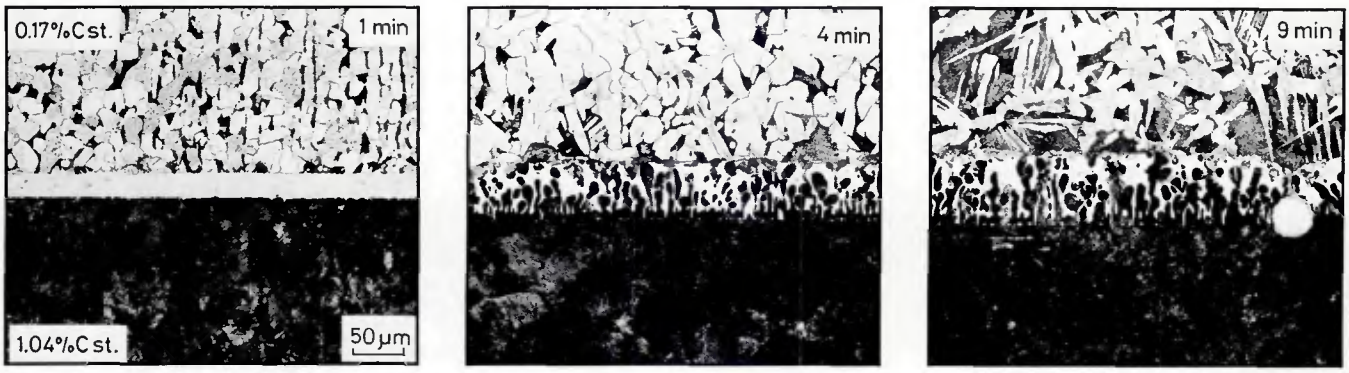

Fig. 8 — Growth of columnar phase in dissimilar joint with a joint clearance of 35 μm (0.0014 in.), brazed at 1125°C (2057°F) for 1, 4 and 9 min (200X)

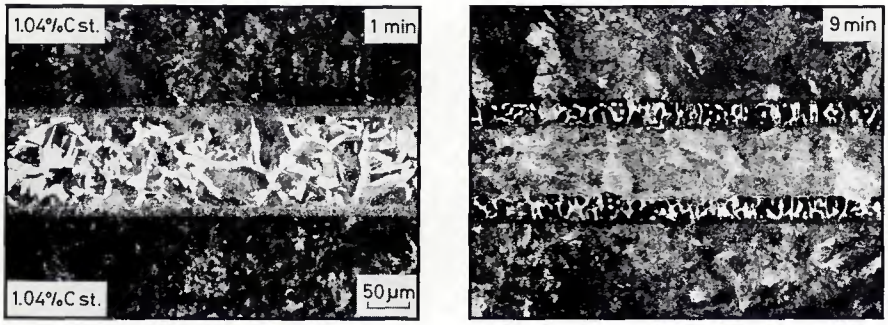

Fig. 10 — Microstructure of the similar high-carbon steel joint, brazed with the special filler metal (BDL) at 1125°C (2057°F) for 1 and 9 min (200×)

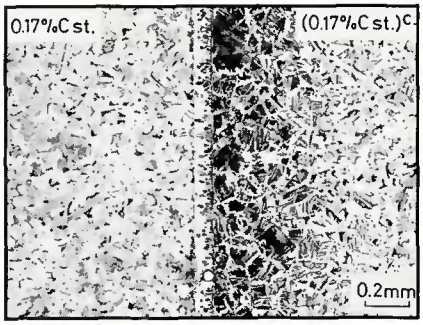

Fig. 12 — Microstructure of one-side carburized low-carbon steel joint with a root opening of 50 μm (0.002 in.), brazed at 1125°C (2057°F) for 9 min (50×)

strength of both similar joints decreased as the holding time increased. This could account for the widening of the joint clearance as the dissolution and deposit of base metal proceeds — Figs. 9, 10. It is important, therefore, to establish the optimum holding time for obtaining the highest impact strength, especially with low-carbon steel joints.

Applying a Carburization

The second method to utilize dissolution and deposit of base metal on a similar low-carbon steel joint is to apply a reducing flame to one of the base metals prior to brazing. Due to the one-sided carburization, the columnar phase (same as that in a dissimilar joint) forms from the carburized low carbon steel — Fig. 12.

Figure 13 illustrates the results of the impact tests on low-carbon steel joints, carburized on one side and having no joint clearance. The microstructures of the joint are shown in Fig. 14. The CUN impact strength of the joint increased to 89.2 J/cm^2 (52.6 ft-lb). This was nearly equivalent to that for the low-carbon steel joint brazed with the special filler metal (BDH) — Fig. 11. In the case of a 1-min braze specimen, the CUN impact strength of the joint was relatively low — 57.9 J/cm^2 (34.2 ft-lb), although both base metals had already been united with the columnar phase. This might be due to the existence of high-carbon parts near the braze interfaces; and as stated earlier, carbon in steel decreases the toughness. Indeed, the CUN impact strength of the joint carburized on one side with an effective case depth of 0.8 mm (0.032 in.) was below 24.5 J/cm^2 (14.5 ft-lb) because the thick carburized layer did not disappear, even though holding time was 16 min.

Hence, when applying one-sided carburization to the similar low-carbon steel joint, it is important to minimize the case depth so that the dissolution and deposit of base metal can occur, *i.e.*, uniting both base metals with the columnar phase, and extinguishing the high-carbon parts by diffusion treatment.

Likewise, when the similar high-carbon

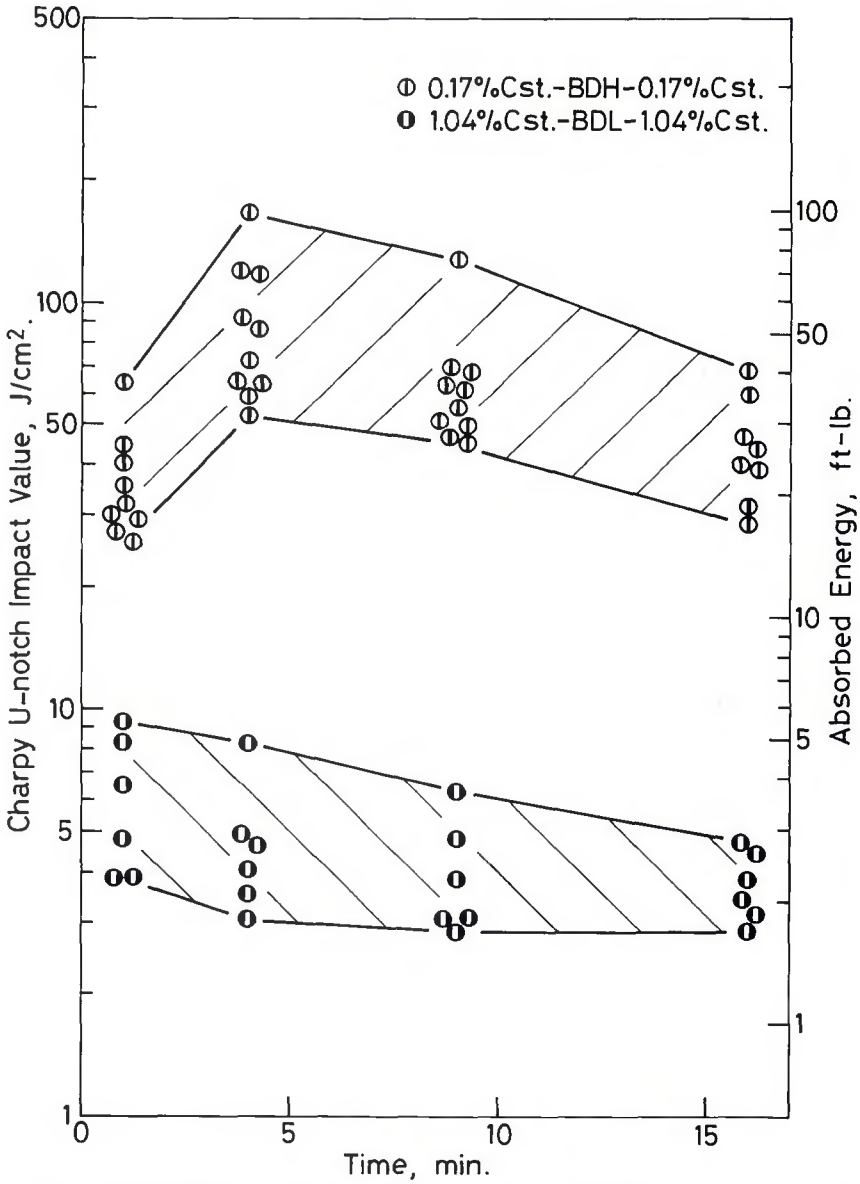

Fig. 11 — Effect of using the special filler metal on the impact strength for the similar joints, brazed at 1125°C (2057°F)

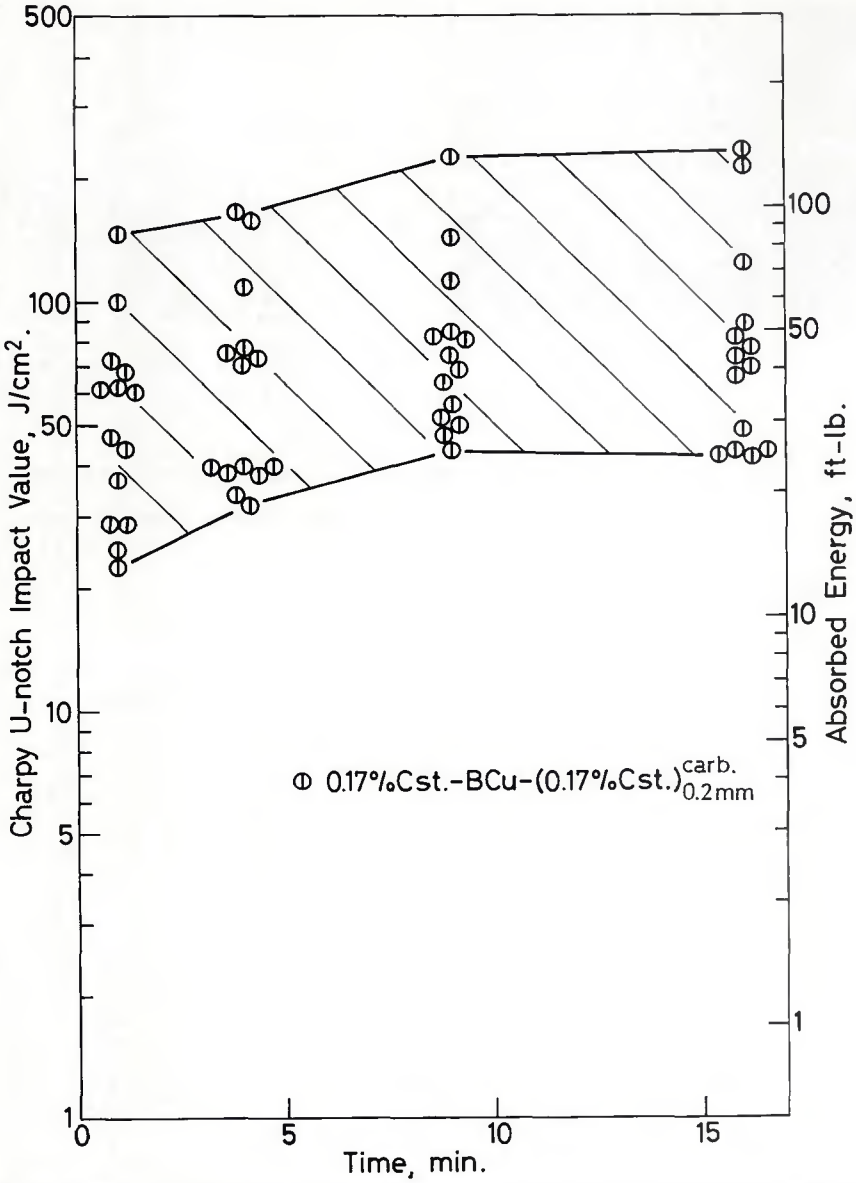

Fig. 13 — Effect of one-sided carburization on the impact strength of the low-carbon steel joint with no joint clearance, brazed at 1125°C (2057°F)

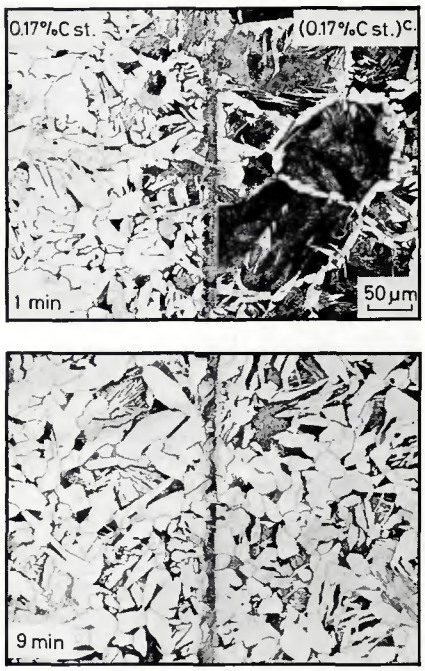

Fig. 14 — Microstructure of one-side carburized low-carbon steel joint with no root opening (press fit), brazed at 1125°C (2057°F) for 1 and 9 min (200X)

steel joint was decarburized on one side prior to brazing, both base metals were united by the columnar phase that formed from the nondecarburized, high-carbon steel side. However, an increase in the impact strength of the joint would undoubtedly be small by the same reasoning as discussed previously in the special filler metal (BDL) section — Fig. 11.

Conclusion

1. In brazing low-carbon steel (0.17 C) to high-carbon steel (1.04 C) with Cu filler metal, the Charpy U-notch (CUN) impact strength at room temperature is increased remarkably from 2.9 J/cm² (1.7 ft-lb) to 27.2 J/cm² (16.0 ft-lb), when both base metals are united by the columnar phase of the Fe/9-12 Cu/1-2 C alloy. This is due to the dissolution and deposit of the base metal.

2. When using a special filler metal consisting of high-carbon steel foil plated with 10-µm (0.0004-in.) thick Cu on both sides for a similar low-carbon steel joint, the CUN impact strength of the similar low-carbon steel joint increased to 89.4 J/cm² (52.8 ft-lb), because both base metals were united by the columnar phase through the foil.

3. Due to the carburizing of one side of the similar low-carbon steel joint to an effective case depth of 0.2 mm (0.008 in.) prior to brazing, a CUN impact strength of 89.2 J/cm² (52.6 ft-lb) was attained because of the columnar phase that developed from the carburized low-carbon steel side.

Acknowledgments

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