Weldability of a New High Strength Low Alloy Cast Steel

Tests show that IN-866 can be welded without preheat in the as-cast and heat treated condition and that ease of cutting, gouging and hardfacing is comparable to mild steel

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Introduction

Cast low alloy steels that employ substantial amounts of carbon to achieve their strength often require preheat and postheat for repair welding, and for many applications, they have inadequate toughness in heavy sections. These limitations become increasingly important as castings are used in highly pressurized lines and as larger castings are needed, for example in the construction and machinery industry.

In order to provide a useful high strength cast steel economically, superior strength and toughness must be attained in heavy sections without sacrificing the quality and processing advantages of mild carbon steel castings. The castings must be free from hydrogen flaking and must be capable of processing through cut off, gouging of defect areas, and weld repair in the as-cast condition. This must be possible without preheat, without limit on weld deposit rate and without the need for control of interpass temperature.

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To meet these objectives a new steel, designated IN-866, has been developed. Table 1 gives the nominal composition of this high strength, low alloy cast steel.

In the normalized and aged condition, the steel has a yield strength of approximately 70 ksi, a tensile strength of 100 ksi, and impact toughness (CVN) at room temperature of about 60 ft-lb. Higher strengths (approximately 105 ksi Y.S.) can be obtained if the castings are quenched and aged, and in this condition, the toughness at room temperature is approximately 35 ft-lb. Some typical properties of samples taken from 2⅜ in. thick keel blocks are shown in Table 2. An example of the fine-grained ferrite structure from the center of a keel block is shown in Fig. 1.

Examinations of the properties and microstructures of heavier sections have shown that, in the normalized and aged condition, the steel can be used successfully in castings up to approximately 6 in. maximum thickness (Ref. 1).

These results demonstrate that two of the objectives — the required high strength, and toughness in heavy sections — have been met.

This paper describes the results of an investigation to determine if the steel can also be welded, gouged, hardfaced, and cut without preheat or postheat treatment under conditions consistent with foundry practice.

Experimental Procedure

Materials

The material used for the tests was obtained from cast keel blocks of two heats. Chemical analysis gave the compositions listed in Table 3.

Before the tests, 1 × 3 × 6 in. pieces cut from the blocks were ground on both surfaces and x-ray

Fig. 1 — Fine-grained ferrite structure at the center of a 2⅜ inch keel block. X100, reduced 45%

Table 1 — Nominal Chemical Composition of IN-866, Wt%

C	Mn	Si	Ni	Mo	Cr	Cu	Al	P	S	Fe
.08/.12	1.4/2.0	.20/.40	.80/1.3	.15/.25	.40/.80	1.1/1.4	.03/.07	.03 max	.03 max	Bal.

Table 2 — Mechanical Properties of Heat Treated 2⅜ In. Thick Castings [a]

Heat Treatment	Y.S., ksi	U.T.S., ksi	% El. 1 in.	R.A., %	CVN (ft-lb) R.T.	0 F	−40 F
1½ h/1650 F/AC + 2 h/1200 F/AC	71.7	100.2	15.5	36.0	37	27	14
2½ h/1700 F/AC + 1½ h/1650 F/AC + 2 h/1200 F/AC	70.8	99.4	13.0	30.0	65	33	21
2½ h/1900 F/AC + 1½ h/1650 F/AC + 2 h/1200 F/AC	71.9	98.8	15.0	32.5	58	30	24

(a) Tensile values are average of duplicate measurements. CVN values are average of triplicate measurements.

and dye-penetrant inspected to insure that the castings were internally sound and free from surface defects.

Cutting, Gouging and Welding Tests

Tests were made to simulate Steps 2, 5, 6 and 12 in the following typical cleaning room procedure:

1. Shake out.
2. Cut off the gates and risers with air-carbon arc or oxyacetylene torch.
3. Blast to clean off the sand.
4. Visual and dye penetrant inspect.
5. Grind or gouge out any defects — no preheat.
6. Weld repair without preheat.
7. Grind.
8. Inspect.
9. Heat treat (in this case at approximately 1650 F/1 h/AC + 1200 F/1 h/AC).
10. Rough machine.
11. Inspect.
12. Weld repair if necessary — no preheat, etc.
13. Stress relieve at approximately 1200 F.
14. Finish machine.

Oxyacetylene Cutting

One inch thick specimens of IN-866 and mild steel were cut using automatic oxyacetylene cutting equipment. The quality of the cut surfaces were compared and the structures adjacent to the surface examined microstructurally.

Air-Carbon Arc Gouging

Grooves were gouged in 1 in. thick pieces of both IN-866 and mild steel using a manual air-carbon arc torch. Photographs were taken to show the quality of the gouges in the two materials and the metallurgical structures adjacent to the gouged areas were examined microstructurally and by hardness testing.

Weld Repair Tests

Low hydrogen electrodes of the E-11018 classification were used to make the simulated weld repair in the crack sensitivity specimens shown in Fig. 2. Electrodes of 5/32 in. diam were used at 150 A and 24 V. The welding schedules were chosen to take into account weld repairs at stages 6 and 12 in the cleaning room procedure and consequently the welding and heat treating sequences were as follows:

1. As-cast blocks, welded, heat treated (1700 F/2 h/AC + 1650 F/1 h/AC + 1200 F/1 h/AC), tested.
2. As-cast blocks, heat treated same as above, welded, stress relieved (1200 F/1 h/AC, tested.

The composition and properties of undiluted deposits made with this electrode are shown in Table 4. Weldments were restrained by heavy C clamps which were not removed until the completed welds had cooled to room temperature.

After removal of the weld reinforcements, welded specimens were subjected to both x-ray and dye-penetrant checking. Also, transverse sections were polished, etched and examined microscopically for defects.

Table 3 — Chemical Analyses of the IN-866 Castings

C	Mn	Si	Ni	P	Mo	Cu	S	Cr	Al	Fe
.10	1.80	.35	.95	.013	.18	1.2	.011	.58	.094	Bal.
.10	1.69	.32	.97	.015	.19	1.2	.011	.59	.14	Bal.

Table 4 — Electrode Manufacturer's Specifications for E-11018 Electrodes [a]

C	Mn	Si	Ni	Mo	Y.S., ksi	T.S., ksi	% El. (2 in.)	CVN (75 F) ft-lb
.05	1.60	40	1.60	.40	104	115	24	110

(a) Undiluted weld metal

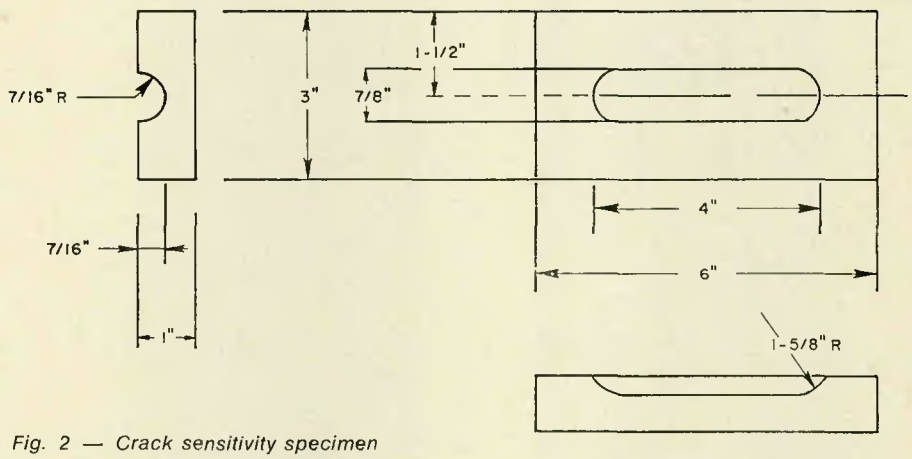

Fig. 2 — Crack sensitivity specimen

Battelle Underbead Crack Tests

In this test, a bead 1¼ in. long was deposited with an E-6010 cellulosic electrode in the center of one 2 × 3 in. face of the sample. After welding the specimen was held for 24 h at room temperature to allow the hydrogen introduced by the cellulosic coating to exert its influence on the heat-affected zone of the weld. After 24 h, the specimen was tempered at 1100 F for 1 h and sectioned for its full length through the weld bead centerline. The longitudinal section containing the weld bead, heat-affected zone and

Table 5 — Electrode Manufacturer's Specifications for Hardfacing Electrode

Rockwell "C" hardness (single layer)	Typical deposit analysis C	Mn	Si	Cr	Applications
36-40 (on 1020 steel)	1.8	2.2	.35	2.7	Bucket lips, teeth, dozer blades, crusher rolls, auger bits

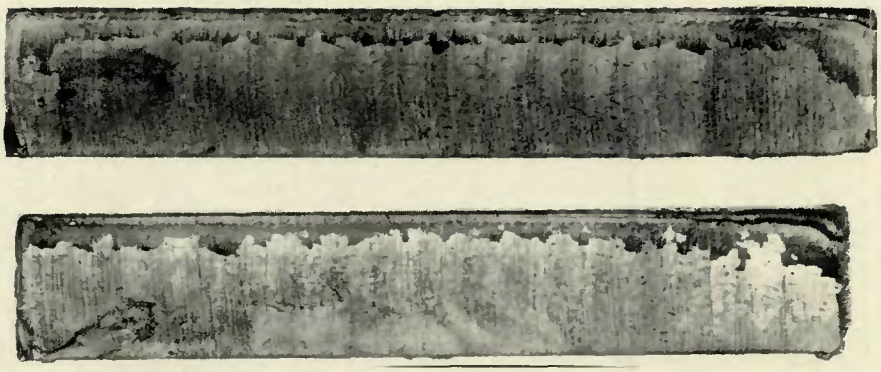

Fig. 3 — Oxyacetylene cut surfaces: (top) mild steel; (bottom) IN-866. Three-fourths actual size

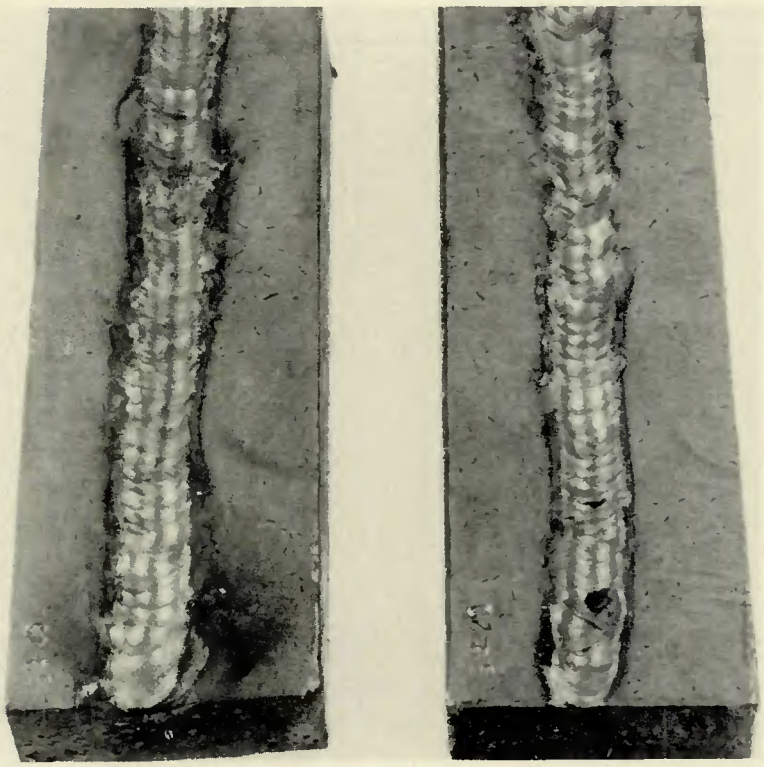

Fig. 4 — Air-carbon arc gouged sections of (left) IN-866 and (right) mild steel. Three-fourths actual size

Fig. 5 — Cross section of battelle specimen. X1.75 actual size

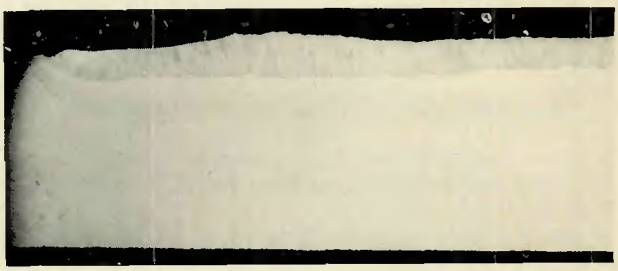

Fig. 6 — Transverse section of repair weld. X2.15 actual size

base plate was polished, etched and examined at 30X magnification.

Hardfacing Tests

For the hardfacing tests on the cast material, an electrode recommended for the surfacing of bucket lips was employed. The manufacturer's typical deposit analysis and as-deposited hardness are shown in Table 5. The hardfaced piece was sectioned down through the surface layer and examined for cracking. The hardness of the hardfaced layer was also measured.

Results and Discussion

Response to Welding, Cutting and Gouging

X-ray and dye-penetrant testing of the pieces cut from the keel block showed them all to be sound. The same tests run on the completed weldments similarly revealed no tendency towards base metal or weld metal cracking. When the response of IN-866 to oxyacetylene cutting was compared with that of mild steel, good clean cuts were obtained in both instances (Fig. 3). In an examination of the ease with which it can be air-carbon arc gouged, IN-866 was again judged to be similar to mild steel (Fig. 4). However in order to check further on the influence of the gouging process on the IN-866 base metal, Vickers hardness readings were taken at 30 kg loads immediately adjacent to the gouged region. The average of the hardness readings was 367 VHN. This is slightly above the 350 VHN which has been suggested as a threshold above which cracking can occur (Ref. 2) but in these tests there was no evidence of cracking.

There was also no cracking of the IN-866 in the Battelle underbead crack tests made with E-6010 electrodes, (although the weld metal contained cracks). Figure 5 illustrates a typical cross section of these specimens.

Macroscopic evaluation of the slices from the completed crack sensitivity weldments (Fig. 6) revealed that sound weldments were produced under all conditions.

Properties of Weldments

After heat treatment, the hardness of the weld metal, heat-affected zone and base metal were relatively low and well below the level at which cracking would be expected (Table 6). The heat-affected zone hardness, for example, was a maximum of approximately 240 VPN. In the as-welded condition hardnesses of approximately 300 VPN were measured.

When IN-866 is welded in the as-cast condition and then given a complete postweld heat treatment the resulting strengths, measured on transverse specimens, are approximately 70 ksi yield strength and 95 ksi tensile strength. The impact toughness of the weld metal is approximately 95 ft-lb CVN at room temperature (Table 7). Welds made in heat treated material and given only a postweld stress relief had similar properties. Heat-affected zone toughness in both cases was also high; i.e., approximately 70 ft-lb CVN at room temperature. In all instances the transverse tensile specimens failed in the heat-affected zone.

The hardfacing of an IN-866 block was carried out without difficulty and examination of sections through the surface showed the deposit to be sound with a hardness of 30 Rockwell C. Although this is less than the manufacturer's reported values of 36-40 Rc for deposits on 1020 steel (Table 5), it is an acceptable level of hardness.

Significance of Results

The results of the foregoing tests indicate that IN-866 is not sensitive to cracking and that consequently it should be possible to cut, gouge and weld it in the foundry without the need for preheating or postheating. This simplification of cleaning room procedure should lower the costs of products made with the alloy. Hence, the new cast steel appears to be an example of a higher alloyed material that is nevertheless cost-effective because of the lower processing costs it requires.

It is significant that the weldability was good in spite of the relatively high carbon equivalent of the alloy. Using a common formula (Ref. 3):

$$CE = C + Mn/6 + Ni/20 + Cr/20 + Cu/40 - Mo/50 - V/10$$

the carbon equivalent of the alloy is approximately 0.50. At this level a steel would usually be weldable only with difficulty and would probably require preheat. These equations, however, were developed for quenched and tempered steels which are carbon-hardened.

How well they apply to other types of alloys does not seem to have been established. Certainly the results of the tests in this paper suggest that IN-866, even with the high carbon equivalent, is very resistant to cracking.

Conclusions

1. A new cast low alloy steel, IN-866, has been developed, and combines yield strengths in the range 70-100 ksi with good toughness in heavy sections.
2. The steel can be welded in both the as-cast and heat treated condition with commercial welding electrodes. No preheat is required and the strength and toughness of the weldments meet all requirements.
3. IN-866 can be readily cut using the oxyacetylene process and readily gouged by air-carbon arc. Ease and quality of cutting and gouging are comparable to those of mild steel.
4. The steel can be hardfaced with a response comparable to that of mild steel.

References

1. Donachie, S. J., "An Age-Hardening, High-Strength, Low Alloy Cast Steel," to be published.
2. "Background for the Development of Materials to be Used in High Strength Steel Structural Weldments," DMIC Report 172, 1962.
3. Winterton, K., "Weldability Prediction from Steel Composition to Avoid Heat-Affected Zone Cracking," *Welding Journal*, Vol. 40 (6), June 1961, Res. Suppl., pp 253-s to 258-s.

Table 6 — Vickers Hardness Traverses Across Weld, Heat-Affected Zone and Base Metal (a)

Weld no.	Base metal	Weld metal	HAZ
3814 (b)	225	227	218
3816 (c)	218	266	236

(a) Average of readings (10 kg load).
(b) As-cast + weld + heat treat (1700 F/2 h/AC + 1650 F/1 h/AC + 1200 F/1 h/AC).
(c) Heat treat + weld + stress relief (1200 F/1 h/AC).

Table 7 — Mechanical Properties of the Repair Welds (E-11018 Electrode)

Tensile Properties

Base plate condition (a) Preweld	Postweld	Y.S., ksi	T.S., ksi	% El. (1 in.)	R.A. %	Failure
As-cast	Condition "A"	71.0	95.7	12	30.0	HAZ
Condition "A"	1200 F/1 h/AC	73.9	94.7	10	39.0	HAZ

Impact Properties at Room Temperature

Base plate condition (a) Preweld	Postweld	Notch location	Ft-lb
As-cast	Condition "A"	Weld	95
As-cast	Condition "A"	Fusion line	70
Condition "A"	1200 F/1 h/AC	Weld	87
Condition "A"	1200 F/1 h/AC	Fusion line	72

(a) Condition "A": 1700 F/2 h/AC + 1650 F/1 h/AC + 1200 F/1 h/AC

Discussion

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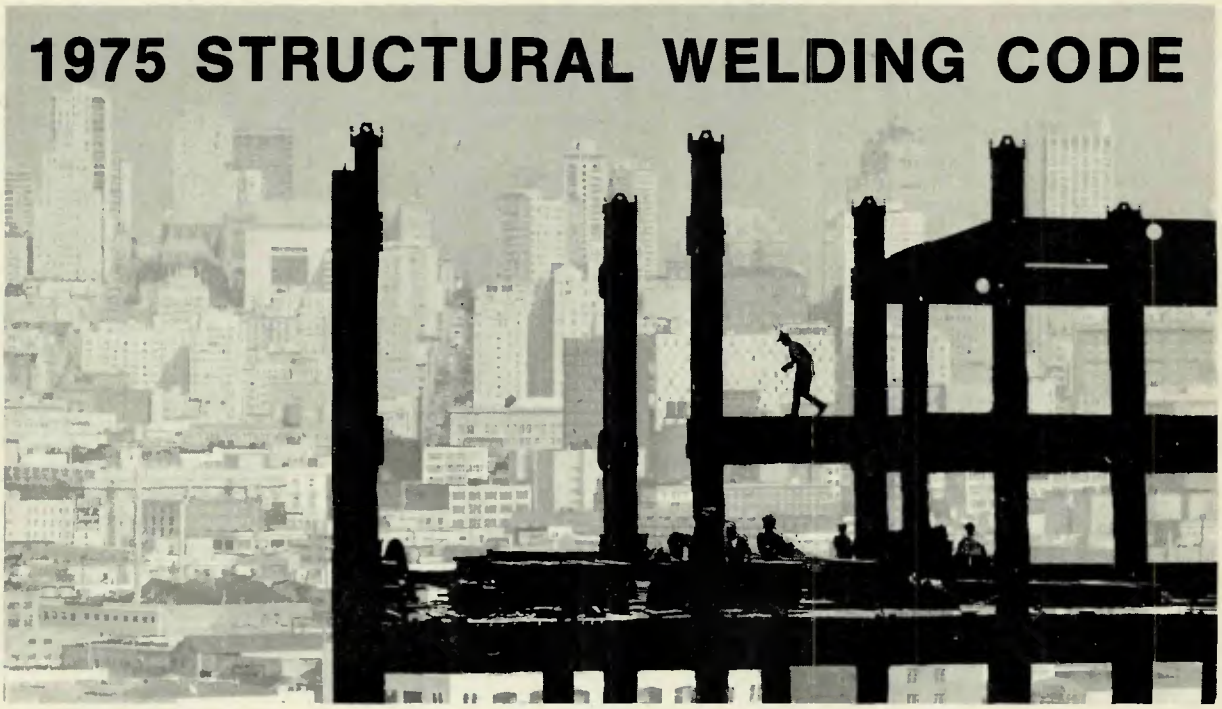

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