Weldability of Forged AISI 4130 and 1020 Mn Steels

1020 Mn steel is a cost effective alternative to AISI 4130 steel, and Controlled Thermal Severity test results indicate that 1020 Mn is less susceptible to cracking

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ABSTRACT. AISI 4130 steel is a commonly used material of construction in oil field applications. Especially during field welding, one needs to be concerned with the degree of latitude that can be tolerated in the control of welding process, procedures and electrodes.

The objective of this program was to find a cost effective alternative to 4130 that would be "more forgiving" in a field welding situation. The primary concern was the cracking tendency due to the hardenability of 4130. Two tests—the controlled thermal severity test and the Battelle Underbead test—were employed to evaluate weldability. The variables studied in the program were welding process (shielded metal arc and submerged arc), electrode type, moisture and plate thickness. Carbon equivalent data from 57 production heats of 1020 Mn steel and 102 production heats of 4130 steel were analyzed and histograms plotted.

The principal findings of the program were:

1. 1020 Mn steel is a cost effective alternative to 4130 steel based upon the expectation of greater latitude in control of welding process variables in a field welding situation. It was shown by means of the bithermal and trithermal controlled severity tests that 1020 Mn is less susceptible to cracking than 4130. Calculating weldability indices from the carbon equivalent confirms that the preheat requirements of 1020 Mn should be at least 100 F (37.8 C) lower than those of 4130.
2. In the controlled thermal severity tests, welds made with E6010 electrodes demonstrated greater cracking tendency than E7018 for both 4130 and 1020 Mn, under both bithermal and trithermal configurations, and in plate thicknesses of 1 in. (25.4 mm) and 1½ in. (38.1 mm). Submerged arc welds made with dry flux did not crack in 4130 or 1020 Mn. When the flux was intentionally moistened, cracking was encountered in the trithermal condition of 1½ in. (38.1 mm) thick 4130, but not in 1020 Mn.
3. Results with the Battelle test, which is not as sophisticated analytically as the controlled thermal serverity test, confirmed the results with the latter. Cracking was observed in both 4130 and 1020 Mn welded with E6010 electrodes but not with E7018 electrodes.

Table 1—Composition of Base Materials, %

Element	AISI 4130	1020 Mn
C	0.33	0.22
Si	0.29	0.33
Mn	0.48	1.23
Mo	0.20	0.10
Cr	0.92	0.31
V	0.048	0.029
S	0.012	0.015
P	0.011	0.018

Introduction

Although AISI 4130 steel has served many applications in oil field products, its high hardenability does generate concern with the degree of latitude that can be tolerated during field welding as regards control of welding process, procedures and electrodes.

Initial conversations with a forging vendor indicated that a high manganese steel, termed 1020 Mn, might be a cost effective substitute for 4130 and because of its lower hardenability would be "more forgiving" during field welding operations. As regards strength, design requirements dictate a yield strength above 60 ksi (415 MPa).

A program was therefore undertaken to compare the relative "weldability" of 4130 and 1020 Mn.

Materials and Procedures

The compositions of the two base metals are shown in Table 1. The 4130 was available in 4 in. (101.6 mm) × 4 in. (101.6 mm) × 8 in. (203.2 mm) forged sections, and tensile and Charpy specimens were removed from the locations shown in Fig. 1. The 1020 Mn test material was taken from a 2 in. (50.8 mm) thick by 4 in. (101.6 mm) wide ring rolled forging which was cut into 8 in. (203.2 mm) lengths. The specimens in this material were removed as shown in Fig. 2.

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Tensile tests were conducted on 0.505 in. (12.82 mm) triplicate tensile specimens. Fifteen Charpy V-notched specimens were utilized to develop a transition curve from −50 F (−46 C) to 150 F (65.6 C).

Weldability Tests

Two well-known weldability tests were selected to evaluate the weldability of the AISI 4130 and the 1020 Mn. These were the controlled thermal severity test (CTS)[1] and the Battelle longitudinal underbead test.[2] Both of these tests have been utilized to develop weldability data on a wide range of steels, and the testing procedures are well documented in the literature.

Briefly, the CTS test provides a range of weld thermal conditions by varying the number of heat flow paths and the thicknesses of plates. As Fig. 3 shows, one test weld has two heat flow paths and the other has three paths. These welds are referred to respectively as bithermal and trithermal welds.

Each ¼ in. (6.35 mm) of plate thickness also represents a thermal severity number (TSN) of one so that the variations in plate thickness can be accounted for analytically. For example, our 1½ in. (38.1 mm) thick tests would have a TSN of 12 for the bithermal weld and 18 for the trithermal weld. The results are evaluated according to the TSN below which cracking does not occur.

Assembly of the CTS tests was accomplished by mating two ground surfaces and tightening a ½ in. (12.70 mm) bolt to 75-80 ft-lb (101.74-108.38 J). Next the two 3 in. (76.2 mm) anchor welds were deposited on the 7 in. (177.8 mm) sides as shown in Fig. 3; the assemblies were then cooled to room temperature prior to making the test welds.

Figures 4, 5, and 6 show the dimensions of the three assemblies selected for this investigation. The modified design, shown in Fig. 6, was adopted to permit the submerged arc tests to be ganged together and fitted with runoff tabs.

After welding and aging, the test plates were sectioned as shown in Fig. 7 for metallographic examination. Note that the welds could be examined at three points along their length.

CTS assemblies were welded using the shielded metal arc process with E6010 and E7018 electrodes and the submerged arc process with an F62-EL12 flux-electrode filler metal combination. The latter welds were made with both dry and damp flux to show the influence of poor flux control.

Material thicknesses were 1½ in. (38.1 mm) and 1 in. (25.4 mm) for the covered electrode tests and 1½ in. (38.1 mm) for the submerged arc tests.

The Battelle longitudinal underbead test which is not as sophisticated analytically as the CTS test is evaluated by simply measuring the amount of underbead cracking in a block of steel which has been welded under controlled conditions in a water bath heat sink. Data from this test were not developed to the point where weldability predictions could be made for conditions other than those used in the actual test. The Battelle test set-up utilizes a 2 in. (50.8 mm) × 3 in. (76.2 mm) × T block of steel immersed in a water bath to within ½ in. (12.70 mm) of the top surface. Although this test is not as versatile as the CTS test, it was considered useful to compare the results of two radically different weldability tests on our base thickness of 1½ in. (38.1 mm) material.

Results and Discussion

Tensile properties of the base materials are shown in Table 2, and impact

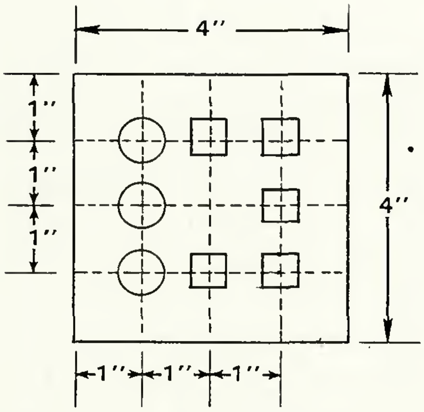

Fig. 1—Location of round tensile and square Charpy specimens in AISI 4130 steel

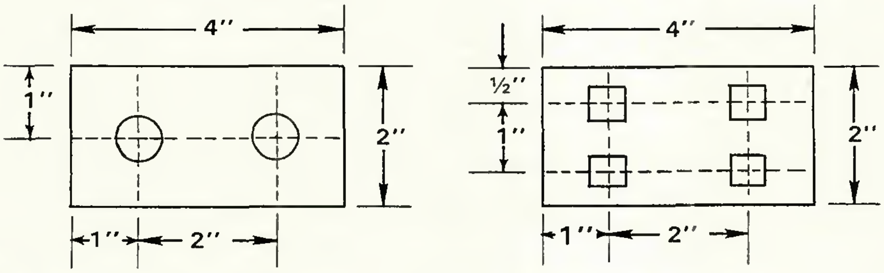

Fig. 2—Location of tensile (left) and Charpy specimens (right) in 1020 Mn steel

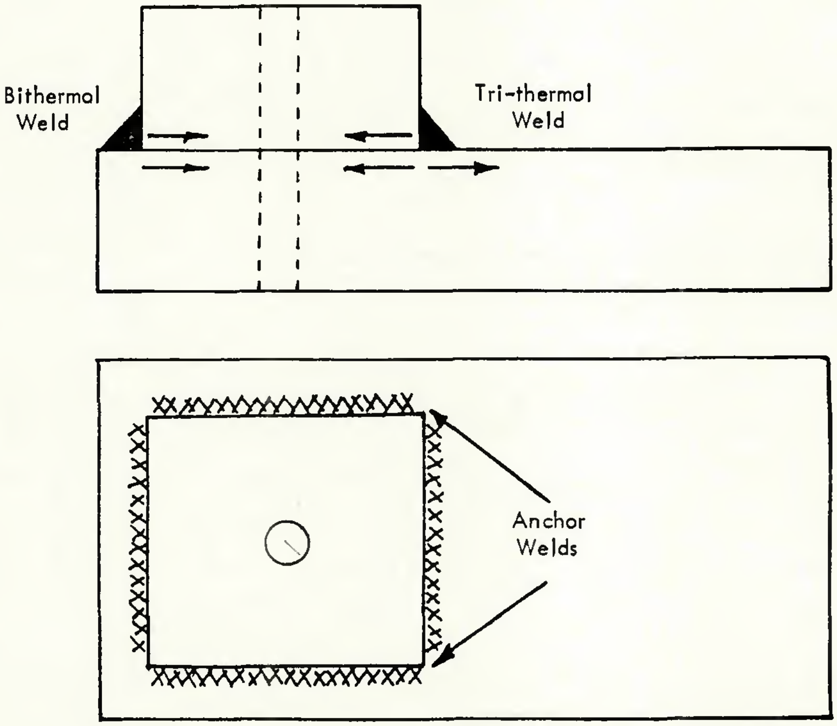

Fig. 3—Sketch showing heat path flows and anchor welds on CTS test

properties in Fig. 8. A typical cross-section and underbead microstructure from the CTS tests are shown in Fig. 9. The results from metallographic examination of all of the cross-sections are given in Table 3.

The data in Table 3 clearly show that a cellulose-coated electrode such as E6010 will cause cracking in either the 1020 Mn or the AISI 4130. The 1020 Mn may have slightly better weldability with E6010 electrodes, but the improvement in weldability is certainly not enough to ensure crack-free welds.

With the E7018 electrodes no cracking occurred in the 1020 Mn, but the AISI 4130 still exhibited some cracking in the trithermal welds. This indicates that the 1020 Mn has somewhat better weldability than the AISI 4130 and that no problems should be experienced when welding with low hydrogen electrodes on at least up to 1½ in. (38.1 mm) thick 1020 Mn.

The submerged arc data also show that both of the steels will give crack-free welds when welded according to good practice; however, when a small amount of moisture is added to the flux, cracking occurs in the AISI 4130 but not in the 1020 Mn.

The 1 in. (25.4 mm) thick tests which were run to confirm the weldability index did not provide the expected results; however, from the limited data on the 1 in. (25.4 mm) thick steel it appears that the 1 in. (25.4 mm) material may still be over the thickness necessary to develop an accurate weldability index. Because the 1 in. (25.4 mm) data are very similar to the 1½ in. (38.1 mm) data, we may be above a threshold over which the changes in weldability are not readily discernible. Additional tests to confirm this theory were not performed; however, calculated weldability indices from chemical composition and BWRA's* data indicate considerably thinner plates would be necessary to determine the weldability index.

Hardness traverses through the heat-affected zones of the CTS test welds showed considerable variation. However, the average peak hardness of the 1020 Mn is 467 Knoop vs. 544 Knoop for the AISI 4130.

A typical cross-section of a longitudinal underbead test specimen from the Battelle weldability test is shown in Fig. 10. The E6010 type electrodes again produced underbead cracking in both steels. No cracking was detected in any of the Battelle-type test specimens welded with E7018 low hydrogen type electrodes. Thus, these results generally confirm the observations made from the CTS tests.

Carbon Equivalents

Weldability indices can also be calculated from carbon equivalents and some additional BWRA tabular data. Theoretically the results should be the same as those generated with the CTS test. For the steels used in this investigation the BWRA carbon equivalent equation

$$\text{C.E.} = \text{C} + \frac{\text{Mn}}{20} + \frac{\text{Ni}}{15} + \frac{\text{Cr} + \text{Mo} + \text{V}}{10}$$

gives a C.E. of 0.440 for the AISI 4130

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*BWRA—British Welding Research Association . . . now known as The Welding Institute.

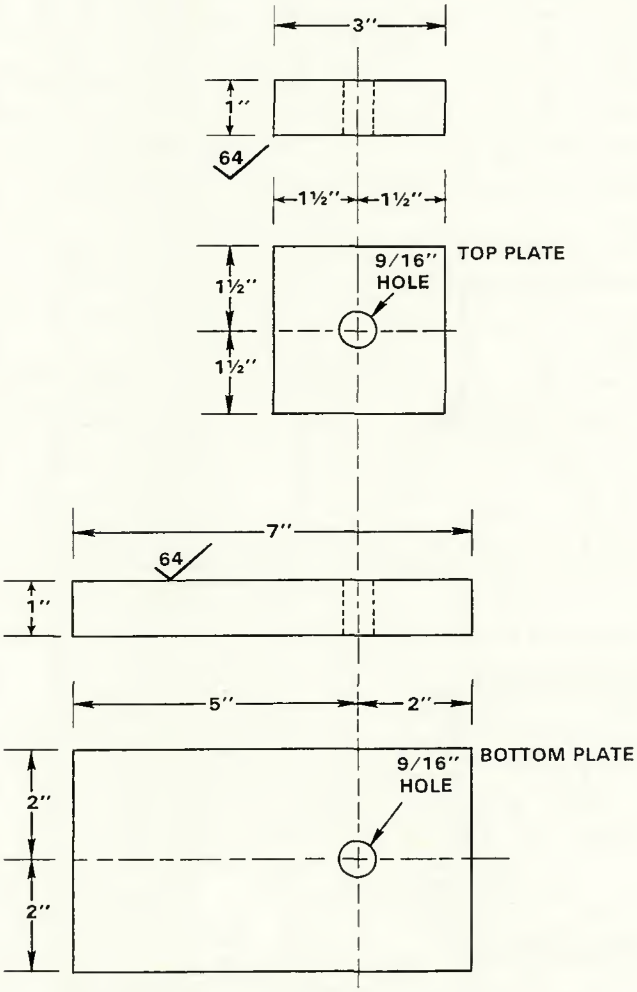

Fig. 4—Plates for 1 in. standard CTS test assembly

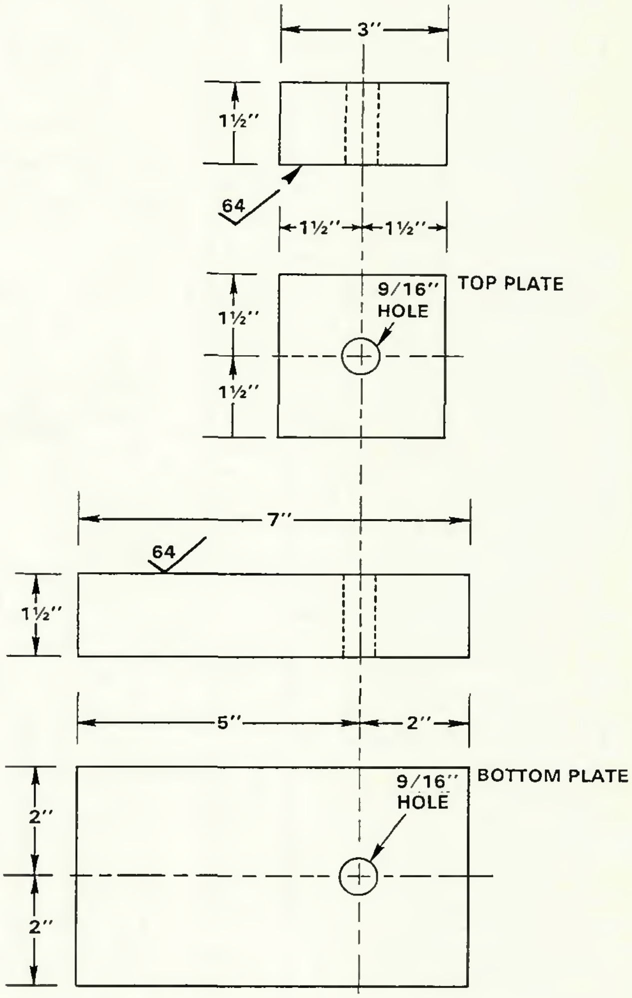

Fig. 5—Plates for 1½ in. standard CTS test assembly

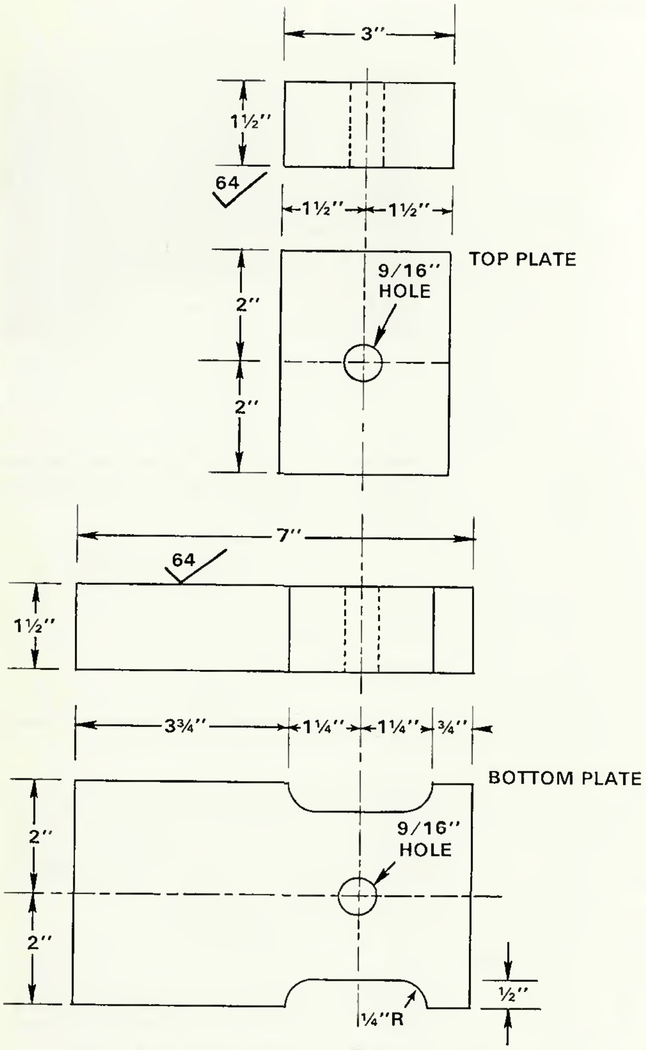

Fig. 6—Plates for 1½ in. modified CTS test assembly

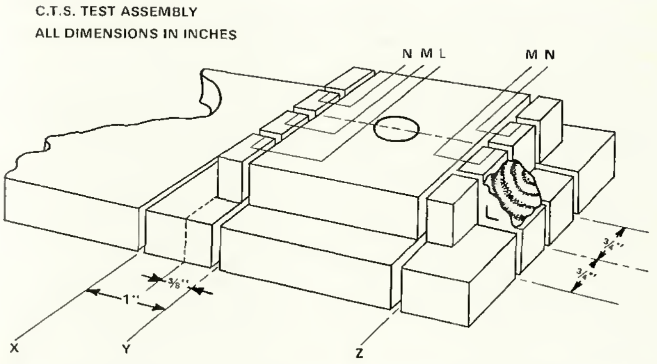

Fig. 7—Method of sectioning CTS test for metallographic examination

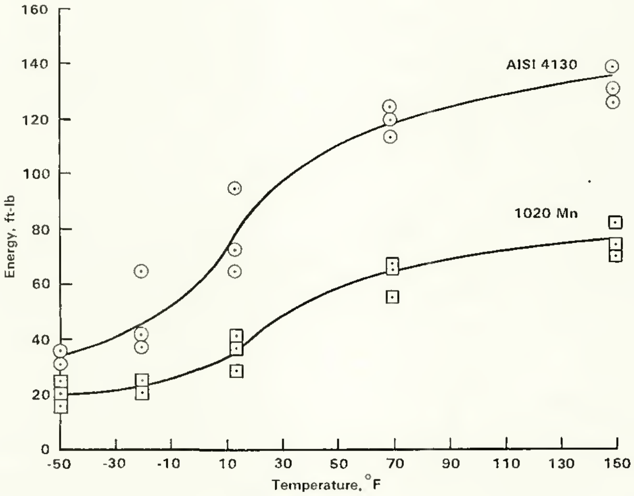

Fig. 8—Charpy impact energy vs. temperature for AISI 4130 and 1020 Mn steels

and 0.325 for the 1020 Mn**.

These values can, by use of the BWRA's data, be used to develop the weldability indices and preheat requirements given in Table 4. According to these calculated values the preheat requirements for the 1020 Mn should be 100 F (37.8 C) lower than those required for AISI 4130. Besides the improved weldability which is reflected in the lower preheat, the time and cost of preheating should also be slightly less.

In addition to the data on the two heats of steel used in this investigation, compositions of 57 other heats of 1020 Mn and 102 other heats of AISI 4130 were obtained for comparison with our test materials. Bar graphs of carbon equivalent vs. percent of total samples for these data are given in Fig. 11. As the data show, the C.E. of our 1020 Mn steel is in the range of the most probable composition for this alloy and our weldability data obviously should represent the most probable results. For the AISI 4130, however, the 0.440 C.E. represents a value in the lower tail of the curve; therefore, our weldability data represent results from a material with a lower than the most probable C.E. Under these circumstances the 1020

Table 2—Tensile Properties

	1020 Mn	AISI 4130
Yield strength, ksi	93.2	74.4
Tensile strength, ksi	115.2	97.3
Elongation in 2 in., %	18.3	24.7
Reduction of area, %	56.0	70.0
Knoop hardness	265	203

Fig. 9—Typical CTS test weld made in 1½ in. (38.1 mm) thick AISI 4130 steel with E6010 electrode: A (left)—cross section, nital etch, ×2.5 (reduced 9% on reproduction); B (right)—heat-affected zone microstructure, nital etch, ×150 (reduced 50% on reproduction)

***More recent carbon equivalent equations have been developed by the BWRA (i.e., Welding Institute), but these equations are limited to C-Mn Steels and do not lend themselves to a comparison such as the one undertaken in this work.*[3]

Table 3—CTS Test Cross-Section Examination Results

Base material[a]	Electrode[b]	No.	Bithermal	No.	Trithermal
1 in. 4130	E6010	S48	Cracked	S47	Cracked
	E7018	T38	No cracks	T37	Cracked[c]
1½ in. 4130	E6010	BC	Cracked	1C	Cracked
		CC	Cracked	2C	Cracked
		DC	Cracked	3C	Cracked
		BD	Cracked	1D	Cracked
		CD	Cracked	2D	Cracked
		DD	Cracked	3D	Cracked
	E7018	BA	No cracks	1A	No cracks
		CA	No cracks	2A	No cracks
		DA	No cracks	3A	No cracks
		BB	No cracks	1B	No cracks
		CB	No cracks	2B	Cracked
		DB	No cracks	3B	Cracked
	SA (dry flux)	U28	No cracks	U27	No cracks
	SA (wet flux)	V28	No cracks	V27	Cracked
1 in. 1020	E6010	P48	Cracked	P47	Cracked
	E7018	O38	No cracks	O37	No cracks
1½ in. 1020	E6010	BY	No cracks	1Y	Cracked
		CY	No cracks	2Y	Cracked
		DY	Cracked	3Y	Cracked
		BZ	Cracked	1Z	Cracked
		CZ	Cracked	2Z	Cracked
		DZ	Cracked	3Z	Cracked
	E7018	BW	No cracks	1W	No cracks
		CW	No cracks	2W	No cracks
		DW	No cracks	3W	No cracks
		BX	No cracks	1X	No cracks
		CX	No cracks	2X	No cracks
		DX	No cracks	3X	No cracks
	SA (dry flux)	R28	No cracks	R27	No cracks
	SA (wet flux)	Q28	No cracks	Q27	No cracks

[a] 1020 is 1020 Mn.

[b] SA is submerged arc.

[c] One of three T37s was "No cracks."

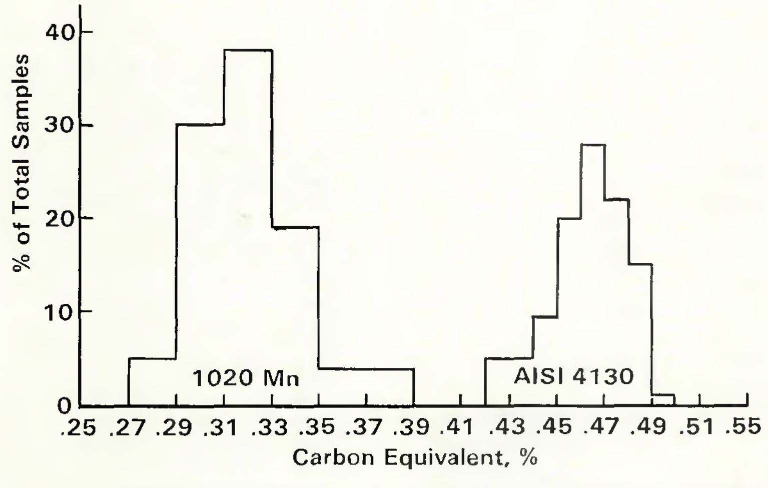

Fig. 11—Distribution of carbon equivalent for 57 heats of 1020 Mn and 105 heats of AISI 4130 steel

Mn steel is very possibly a better alternate choice than our data indicate.

Summary

1. 1020 Mn is a cost effective alternative to 4130 based upon the expectation of greater latitude in control of welding process variables in a field welding situation. It was shown by means of the bithermal and trithermal controlled severity tests that 1020 Mn is less susceptible to cracking than 4130. Calculating weldability indices from the carbon equivalent confirms that the preheat requirements of 1020 Mn should be at least 100 F (37.8 C) lower than those of 4130.

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3. Results with the Battelle test, which is not as sophisticated analytically as the controlled thermal severity test, confirmed the results with the latter. Cracking was observed in both 4130 and 1020 Mn welded with E6010 electrodes but not with E7018 electrodes.

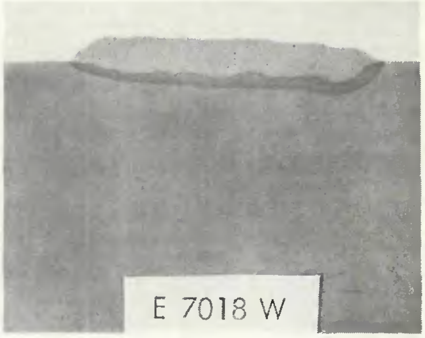

Fig. 10—Typical cross section from Battelle Longitudinal Underbead cracking test. Nital etch, ×1

Table 4—Weldability Data Calculated from Carbon Equivalents

		AISI 4130	1020 Mn
Low hydrogen:	Index	E	C
	Preheat	400	300
Cellulose:	Index	F	E
	Preheat	500	400

References

1. Bradstreet, B.J., *Arc Welding Low Alloy Steels,* British Welding Research Association, 1956.

2. Voldrich, C.B., "Cold Cracking in the Heat-Affected-Zone," *Welding Journal,* 26 (3), March 1947, Res. Suppl., pp. 153-s to 169-s.

3. Coe, F.R., *Welding Steels without Hydrogen Cracking,* British Welding Research Association, 1973.