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Weldability of A Leaded Carbon Steel

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INTRODUCTION

To determine if acceptable quality welds could be made using leaded carbon steel, a limited program was conducted to evaluate the properties of welds made on AISI 12L14 steel. The welds were evaluated by conducting bend tests, hardness tests, and metallographic examinations. The welding procedures were varied by using three different butt weld geometries which are expected to simulate various weld metal cooling rates that would be expected when welding components of different sizes.

MATERIALS AND TESTS

Cold finished bar stock of AISI 12L14 steel was used as the base metal and was separately evaluated by hardness tests, tensile tests, bend tests, and metallographic examination to provide baseline data for comparison with the welded samples. The heat chemical analysis of the 12L14 bar stock was reported by the producer as: (weight percent) carbon 0.08; manganese 1.01; phosphorous 0.06; and sulhur 0.31. The lead content was reported to be in the range 0.15 to 0.35 weight percent. The AISI-SAE specification requirement for 12L14 steel is: (weight percent) carbon 0.15 max.; manganese 0.85 to 1.15; phosphorous 0.04 to 0.09; sulfur 0.26 to 0.35; and lead 0.15 to 0.35.

Welded specimens were reported by Parker-Hannifin Inc. to have been prepared by the metal-inert gas (MIG) welding procedure with As-28/ER705-6 AWS 5.18 filler metal. The three different weld geometries that were made (1/4-inch bevel joint, 3/8-inch bevel joint, and nominal 1/2-inch "J" joint) are shown in Figure 1. The resulting weldments were not full penetration.

All bar stock material below the root of each weld was removed by a band saw. In all cases, the weld reinforcement was ground flush with the bar stock surface to remove any weld undercut. The as-welded samples were finished by surface grinding to obtain the appropriate test specimen dimensions. For all face bend specimens the final test specimen thickness was obtained by grinding the root weld surface, while for all root bend specimens the face weld surface was ground. The test specimen dimensions are described in sections QW-466.2 and QW-466.3 of Section IX of the ASME Boiler and Pressure Vessel Code, 1983 Edition. The face bend, root bend, and side bend specimens with the "J" joint were finished to the standard 3/8-inch thickness. The face bend, root bend, and side bend specimens with the 3/8-inch bevel joint were finished to the standard 3/16-inch thickness. The face bend and root bend specimens with the 1/4-inch bevel joint were finished to a non-standard thickness of 0.1-inch because the weld penetration was insufficient for preparing a 3/16-inch thickness specimen. By optical inspection, all welds appeared to be sound and no weld defects were visible in any of the finished bend test specimens.

Bend tests were conducted using two fixture geometries: a guided-bend roller jig as described in section QW-466.2 and a guided-bend wrap-around jig as described in section QW 466.3 of section IX of the ASME Boiler and Pressure Vessel Code, 1983 Edition. The spacing between the roller jig shoulders and the radius of the forming mandrel are controlled by the thickness of the test specimen and are defined in section 466.1 of Section IX. The exact dimensions of the spacing used in each of the specimen sizes tested is shown in Tables I, II, and III. Additional face bend and root bend tests were carried out on specimens made from the 3/8-inch bevel joint and 1/2-inch "J" weld joint using a wrapped bend test fixture instead of the guided bend test fixture to control better the strain produced in the bend tests.

All hardness tests on base metal and on the weldments were performed on ground specimens prepared in the same manner as the face or root bend specimens. Metallographic analysis was performed on specimens taken from the bend specimens. Tensile tests performed on the base metal were conducted on 3/4-inch and 1-1/2-inch bar stock of cold-finished type 12L14 steel.

RESULTS AND DISCUSSION

Base-metal guided bend tests were conducted on the 12L14 steel bar stock for comparison with the weld metal tests. The test specimens of base metal were 3/8-inch thick and were bent around a 1-1/2-inch diameter mandrel. As shown in Table III, the base metal specimens successfully passed the guided bend test with no evidence of cracking. These results show that the AISI 12L14 base metal steel has adequate ductility to pass a bend test when tested around a 4t diameter mandrel.

Tensile tests were previously conducted on 3/4-inch and 1-1/2-inch thick sections of cold-rolled bar stock of 12L14 [1]. As shown in Table IV, the base metal had an ultimate tensile strength of 74,000 to 76,000 psi and a yield strength of 68,000 to 71,000 psi. Hardness measurements were made on both the base metal from welded samples as well as from the cold-rolled bar stock used in the tensile tests for comparison with the weld metal. As shown in Table IV, the average hardness of the base metal from bend-test specimens was HRB 85 (Rockwell B scale) and the hardness of the cold-rolled bar stock ranged from HRB 81 to 87. Using a reported [2] empirical relationship betwen hardness and ultimate tensile strength for carbon steels, the measured ultimate strength range of 74 to 76 ksi was in good agreement with the range of 73 to 83 ksi predicted from the measured hardness. Thus, for 12L14 steel, the hardness-strength correleation is applicable.

Guided bend tests were conducted on 3/8-inch thick root bend, face bend, and side bend specimens taken from the 1/2-inch "J" weld joint geometry. These were bent around a 1-1/2 inch diameter mandrel. As shown in Table I, all of the specimens (root, face and side bend) failed by cracking along the heat-affected zone (HAZ) of the weldment before completing the full bend test (as shown in Figure 2). The same size specimens were then tested as root-bend and face-bend specimens using the wrapped bend test fixture. This was done because it was recognized that in the guided bend test, the test specimen does not always stay in close contact with the forming mandrel and the specimen may go slightly "pointy" at the maximum bend point. When this happens, the maximum true strain in the specimen will be drastically higher than the expected strain for the specimen thickness and mandrel diameter used in the test. The wrapped bend test avoids this problem and creates a well controlled and known strain in the specimen because the specimen is made to conform to the mandrel at all times. All of the specimens tested with the wrapped-bend-test fixture also cracked at the HAZ boundary in the same manner as the specimens tested with the guided-bend-test fixture. This indicates that the specimens cracked because of reduced ductility (at least when compared with the base metal) in the HAZ of the weld metal and not because of any unusually large strains produced in the guided bend test.

Guided bend tests were also conducted on 3/16-inch thick face bend specimens taken from the 3/8-inch thick bevel weld joint geometry. These were bent around a 3/4-inch diameter mandrel. As shown in Table II, the specimens failed by cracking along the heat-affected zone (HAZ) of the weldment before completing the full bend test (as shown in Figure 2). The same specimen geometries were then tested as face bend and root bend specimens using the wrapped bend test fixture. These specimens also cracked at the HAZ boundary in the same manner as the specimens tested with the guided bend fixture. This indicates that the weldments produced with the procedures used for the 3/8-inch bevel joint geometry also had reduced ductility compared with the base metal and did not pass the bend test.

Although the 0.1-inch-thick face-bend and root-bend specimens taken from the 1/4-inch bevel joint geometry were not tested at this time, they are also not expected to have sufficient ductility to pass the bend test around a 4t diameter mandrel because strain levels are similar to those produced in the 3/8-inch specimens.

Hardness profile measurements were taken across the weld metal, HAZ, and base metal of a bend specimen taken from the 1/2-inch "J" weld geometry. As shown in Table IV, the average hardness of the weld metal was HRB 92 (Rockwell B scale) which corresponds to a tensile strength of about 93,000 psi. This is considerably higher than the average hardness of HRB 85 in the base metal which corresponds to a tensile strength of about 79,000 psi. This may explain why the bend specimens all failed in the HAZ. With the strongly overmatching strength of the weld metal, the ductility of the weld metal, and even more so the HAZ, may be so reduced relative to that of the base metal that the strain to fracture in the HAZ is too low to pass the bend test. This suggests that to successfully weld the leaded carbon steels, the welding procedures and welding electrode should be modified so that the weld metal is at best only slightly stronger than the base metal so that the finished weld can pass the bend test. The failure to pass the bend test does not appear to be related to the leaded carbon steel, but only to the strongly overmatching strength of the weld metal.

To understand further the welding behavior of the leaded carbon steel, a limited metallographic analysis was conducted on the base metal and the weld metal. As shown in Figure 3, the microstructure of the base metal consisted of a ferrite matrix with manganese sulfide inclusions uniformly distributed throughout. Small areas of pearlite were scattered between the ferrite grains as shown in Figure 4. By contrast, the weld metal/HAZ interface showed almost a complete absence of manganese sulfide inclusions in the fusion zone, as shown in Figure 5. This indicates limited melting of the base metal and a very narrow HAZ. Limited EDAX analysis was conducted of the base metal to confirm the identity of the inclusions observed by optical microscopy. As shown in Figures 6 and 7, the X-ray results confirm that the inclusions are MnS. Very small particles that were not visible by optical microscopy were found with the electron microscope and, as shown in Figure 8, were identified by EDAX examination to be primarily lead. No detailed examination was done at this time to determine the effect of welding on the size or distribution of the lead particles.

CONCLUSIONS

(1) Sound welds were produced in the leaded steel (AISI 12L14) using welding procedures currently used for unleaded carbon steels.

(2) The welding procedures used and the welding electrodes used produced a weld metal with a highly overmatching strength so that the ductility of the HAZ was reduced to the point where the welded steel could not pass the conventional ductility (bend) tests.

(3) The inability of these particular welds to pass the bend test is not attributed to the use of leaded steel but is more likely due to the particular welding procedure and welding electrodes used to make these specific welds.

REFERENCES

1. Early, J.G., "Mechanical Properties of a Leaded, Resulfurized, Rephospherized Steel in Various Thermo/Mechanical Conditions" NBSIR 84-2839, January 1984.

2. Society for Automotive Engineers (SAE) Standard J417-83 "Hardness Tests and Hardness Number Conversions."

TABLE I. BEND TEST RESULTS FOR "J"-WELD SPECIMENS

SPECIMEN NUMBER	TEST TYPE(a)	SPECIMEN TYPE	COMMENTS
55-57	G	ROOT	CRACKED ALONG HAZ
50-49	G	ROOT	CRACKED ALONG HAZ
58-58	G	FACE	CRACKED ALONG HAZ
52-53	G	SIDE	CRACKED ALONG HAZ
56-56	W	FACE	CRACKED ALONG HAZ
52-51	W	ROOT	CRACKED ALONG HAZ

GUIDED BEND ROLLER JIG
FINISHED SPECIMEN THICKNESS = t = 3/8 INCH
FORMING MANDREL DIAMETER = 4t = 1-1/2 INCH
JIG SHOULDER SPACING = 6t + 1/8 INCH = 2-3/8 INCH

WRAPPED BEND JIG
FINISHED SPECIMEN THICKNESS = t = 3/8 INCH
FORMING MANDREL DIAMETER = 4t = 1-1/2 INCH

(a) G = GUIDED BEND
W = WRAPPED BEND

TABLE II. BEND TEST RESULTS FOR 3/8 INCH BEVEL WELD SPECIMENS

SPECIMEN NUMBER	TEST TYPE(a)	SPECIMEN TYPE	COMMENTS
37-38	G	FACE	CRACKED ALONG HAZ
33-34	W	FACE	CRACKED ALONG HAZ
34-35	W	FACE	CRACKED ALONG HAZ
39-40	W	ROOT	CRACKED ALONG HAZ
38-39	W	ROOT	CRACKED ALONG HAZ

GUIDED BEND ROLLER JIG
FINISHED SPECIMEN THICKNESS = t = 3/16 INCH
FORMING MANDREL DIAMETER = 4t = 3/4 INCH
JIG SHOULDER SPACING = 6t + 1/8 = 1-1/4 INCH

WRAPPED BEND JIG
FINISHED SPECIMEN THICKNESS = t = 3/16 INCH
FORMING MANDREL DIAMETER = 4t = 3/4 INCH

(a) G = GUIDED BEND
W = WRAPPED BEND

TABLE III. BEND TEST RESULTS FOR BASE METAL SPECIMENS

SPECIMEN NUMBER	TEST TYPE(a)	SPECIMEN TYPE	COMMENTS
1	G	BASE METAL	NO CRACKS
2	G	BASE METAL	NO CRACKS

FINISHED SPECIMEN THICKNESS = t = 3/8 INCH
FORMING MANDREL DIAMETER = 4t = 1-1/2 INCH
JIG SHOULDER SPACING = 6t + 1/8 = 2-3/8 INCH

(a) G = GUIDED BEND

TABLE IV. RESULTS OF HARDNESS MEASUREMENTS

SPECIMEN	LOCATION	HARDNESS HRB	MEASURED ULTIMATE TENSILE STRENGTH, KSI	ULTIMATE TENSILE STRENGTH, KSI, FROM HARDNESS CORRELATION
BEND	BASE METAL	85	-----	79
BEND	WELD METAL	92	-----	93
BAR STOCK	-----	81 - 87	74 - 76	73 - 83

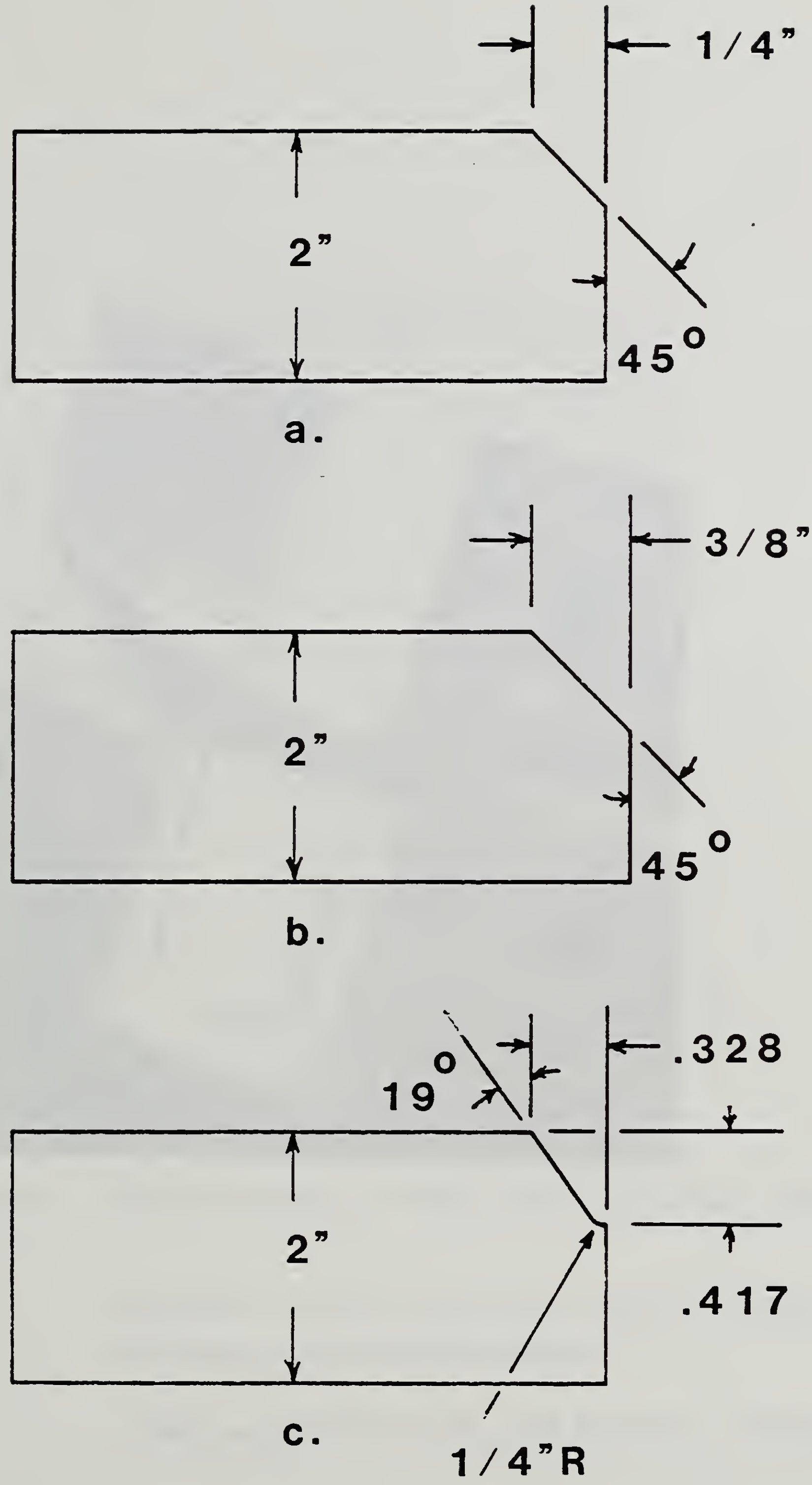


Figure 1. Weld Joint Geometries

a. 1/4 inch bevel

b. 3/8 inch bevel

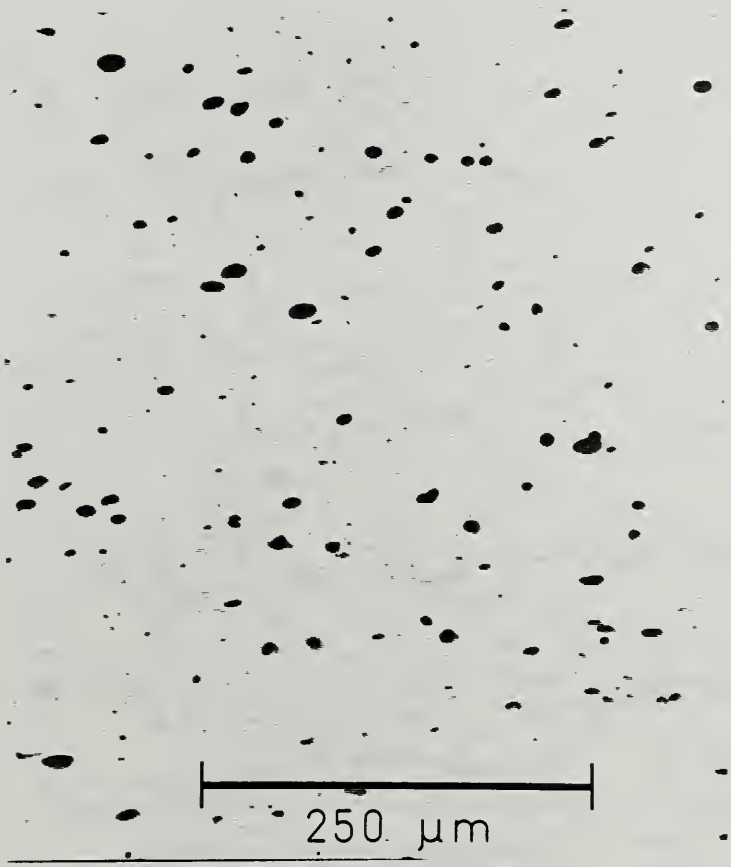
c. "J" joint

a.

b.

Figure 2. Guided Bend Roller Test Specimens

a. 3/16 inch thick, 3/8 inch bevel joint, tensile surface
b. 3/8 inch thick, 1/2 inch "J" joint, tensile surface



Unetched X200

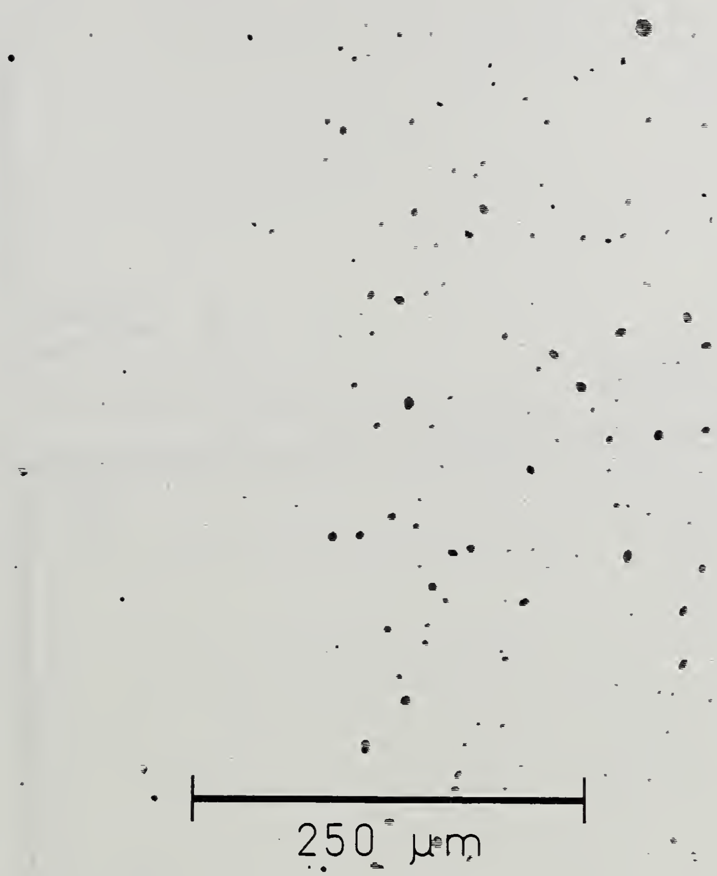
Figure 3. Photomicrograph of AISI 12L14 Steel Base Metal

Manganese sulfide inclusions are distributed throughout the microstructure.

Etch: 2% Nital X200

Figure 4. Photomicrograph of AISI 12L14 Steel Base Metal

Light gray particles are manganese sulfide inclusions. Dark areas between ferrite grains are pearlite.



Unetched X200

Figure 5. Photomicrograph of AISI 12L14 Steel Weld Metal/HAZ Interface

Almost complete absence of manganese sulfide inclusions in the fusion zone (left half of photo)

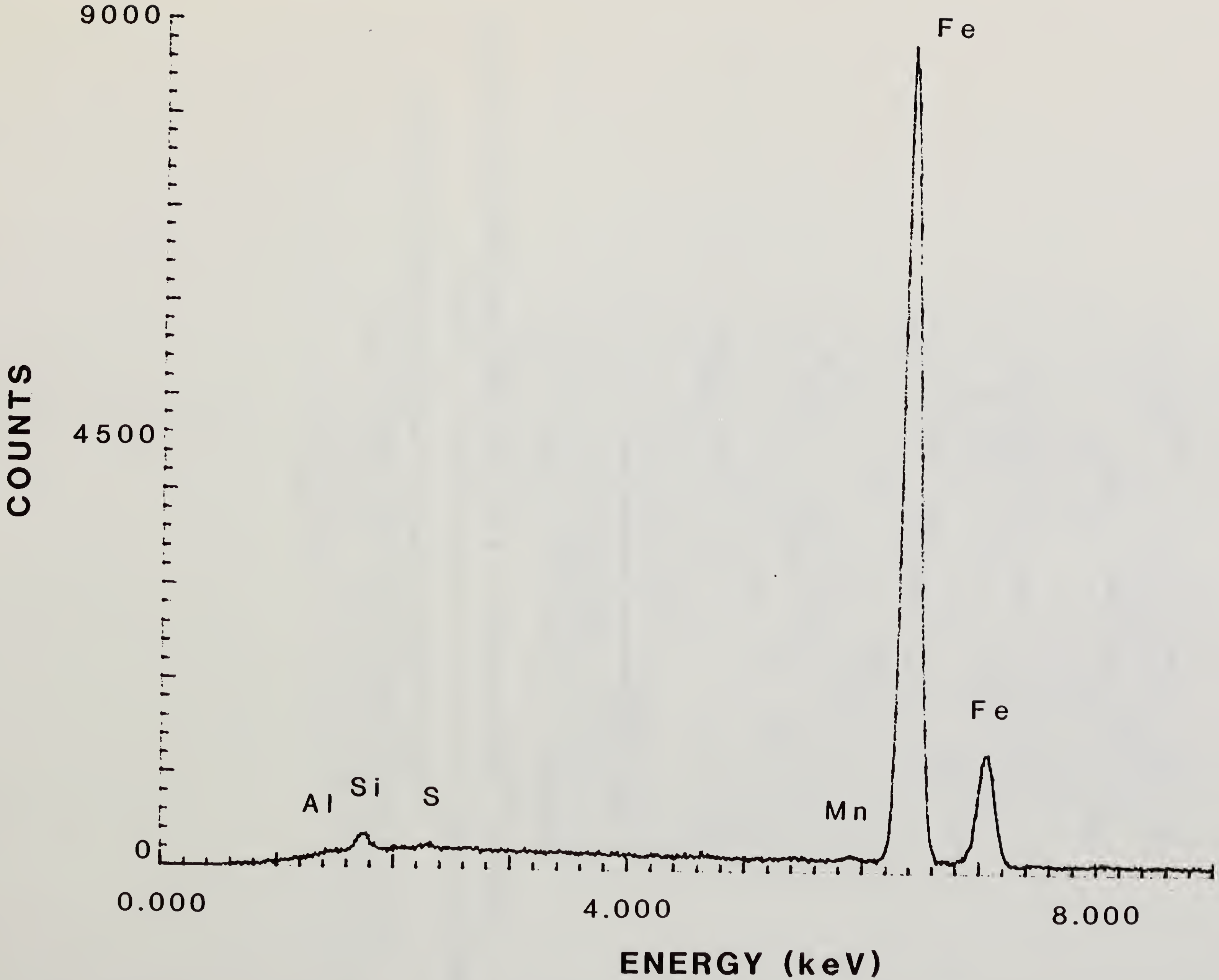


Figure 6. Semi-Quantitative Analysis of AISI 12L14 Steel Bend Test Specimen

X-ray spectra from base metal. Heat analysis: C-0.08; Mn-1.01; P-0.06; S-0.31; Pb-0.15/0.35

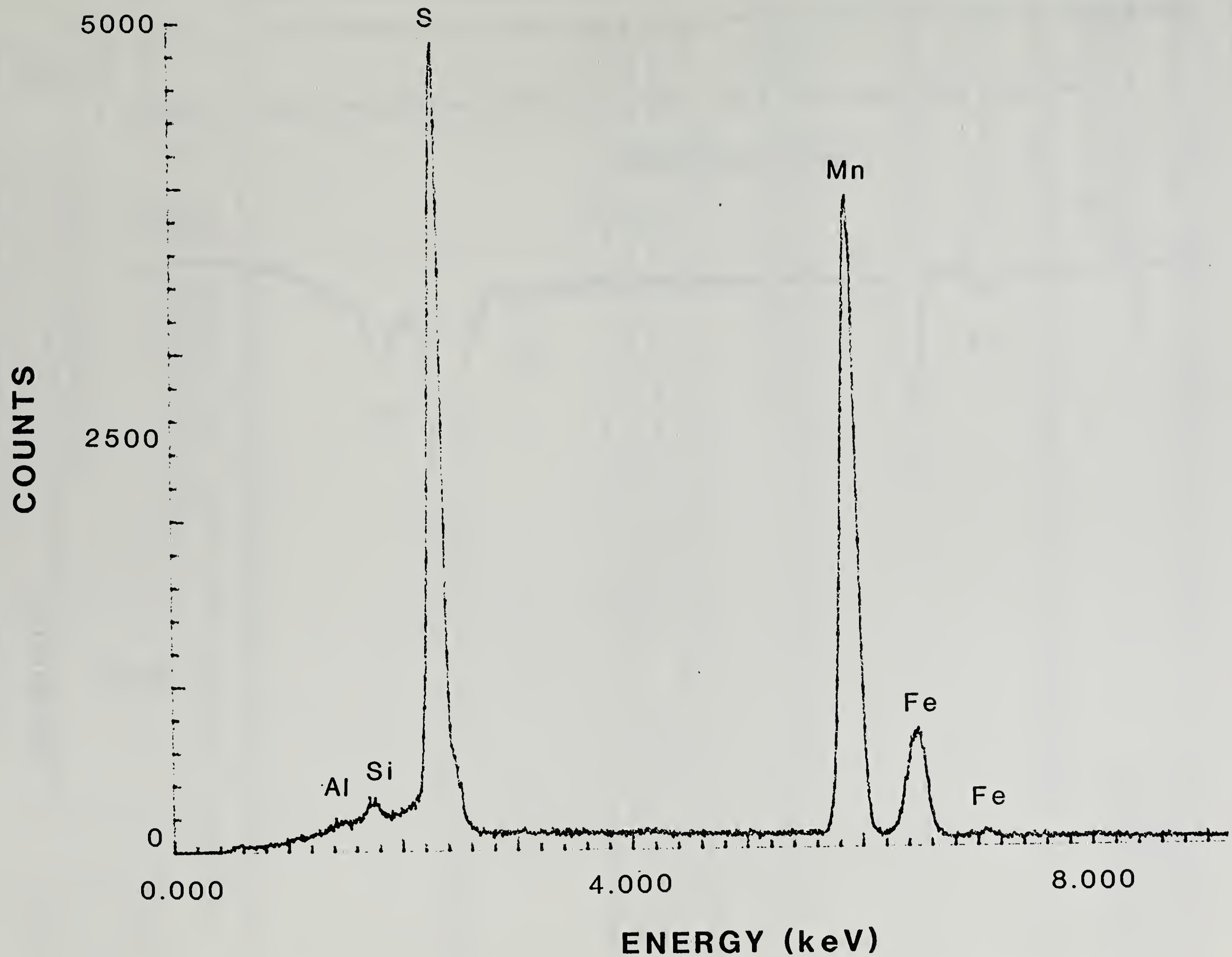


Figure 7. Semi-Quantitative Analysis of AISI 12L14 Steel Bend Test Specimens

X-ray spectra from particles visible in micrographs. Particles are primarily manganese sulfide inclusions.

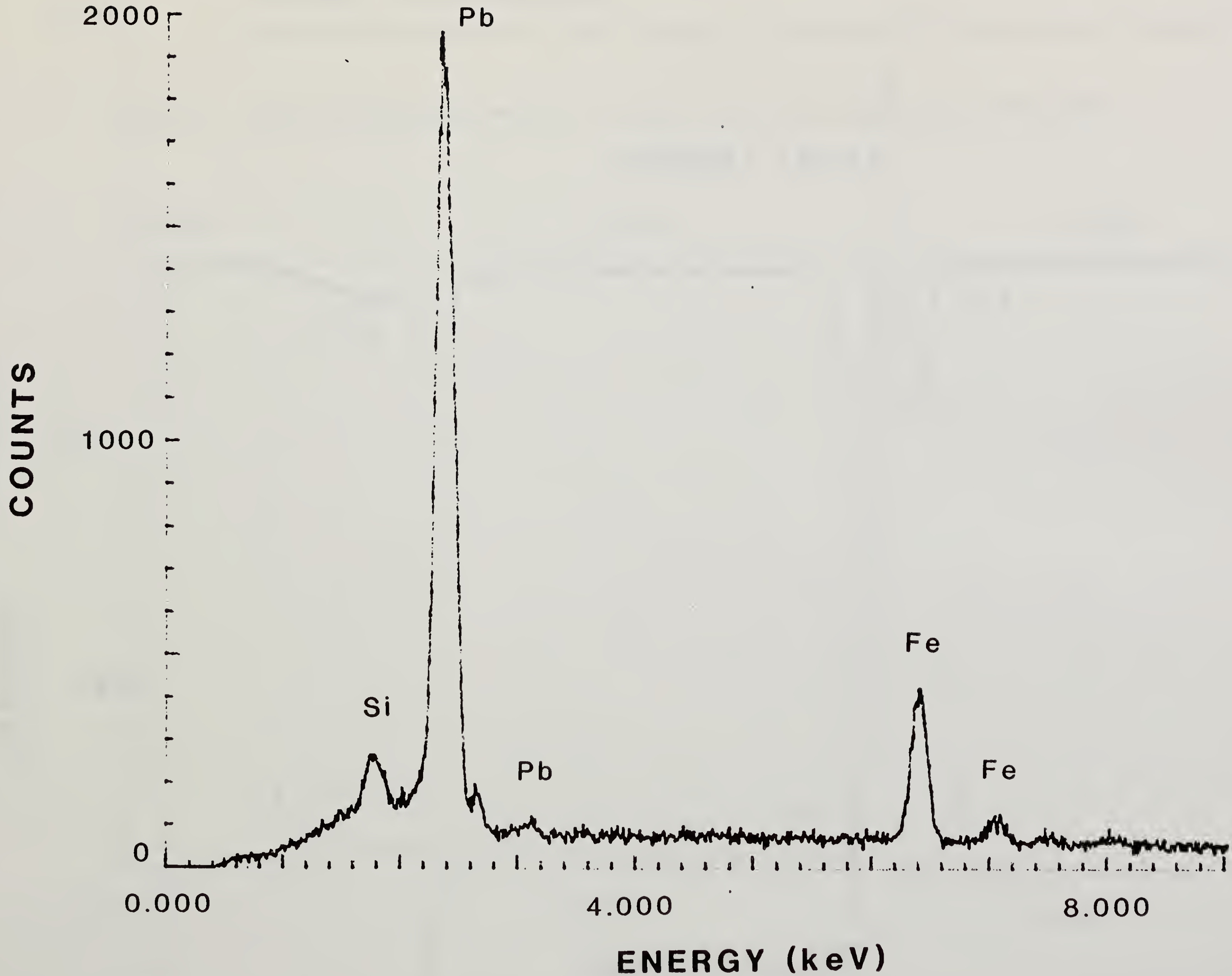


Figure 8. Semi-Quantitative Analysis of AISI 12L14 Steel Bend Test Specimen

X-ray spectra from very small particles not visible in optical micrographs. Particles are primarily lead (Pb).

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Samples of A1S1 12L14, leaded free maching steel were welded using conventional metal-inert gas (MIG) welding procedures. The welds were evaluated for soundness and mechanical properties. Hardness, ductility and microstructure were evaluated to asses the integrity of the welds. Sound welds were produced but the overmatching strength of the weld metal resulted in failure in the HAZ.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Carbon steel; free machining steel; leaded steel; mechanical properties; MIG welding; steel; welding; 12L14 steel.

13. AVAILABILITY

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