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## **GAS-SPRAY REPAIR OF RAIL SURFACE DEFECTS**

October 1991



U.S. Department  
of Transportation  
**Federal Railroad  
Administration**



ASSOCIATION  
OF AMERICAN  
RAILROADS



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| 16. Abstract<br><p>An alternative weld repair process (gas-spray) was devised by the Japanese National Railways (JNR) which incorporates a oxyacetylene flame and a powdered filler metal. The gas-spray process was designed to operate either semi-automatic or fully automatic and was intended to reduce operator errors similar to manually welding with an electric stick arc.</p> <p>In the spring of 1984 at the Facility for Accelerated Service Testing, Transportation Test Center (TTC), Pueblo, Colorado, two JNR gas-spray build-up test welds were made on standard carbon rails on the inside and outside rails of tangent track in the High Tonnage Loop. As a base comparison, two TTC electric arc build-up welds were made a few feet away from them. Both weld processes were intended to simulate a build-up repair of an .080-inch-deep engine burn defect. A battered weld also was repaired with the JNR process in the low rail of a 5-degree curve at the testing facility.</p> <p>The repair welds were tested for a period of 60 MGT under a fully loaded train of 85 cars (33,000 lb wheel load) and four locomotives. After 60 MGT, the JNR welds showed signs of rapid wear and were then removed for evaluation. At the same time, the TTC welds also were removed. A wear rate of .050"/60 MGT was determined for the JNR welds. The TTC test welds located near the JNR welds displayed very little wear and retained most of the original build-up material. The other JNR weld intalled in the 5-degree curve revealed severe wear at 50 MGT and by 60 MGT the original weld deposit was barely visible.</p> |  |  |   |                            |           |
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## EXECUTIVE SUMMARY

The Japanese National Railway's (JNR) gas-spray weld repair process was devised as an alternative method for repairing rail surface defects such as engine burns, rail end batter and fatigue spalling. This method incorporates an oxyacetylene flame and a powdered alloy filler metal and was tested at the Facility for Accelerated Service Testing (FAST), Transportation Test Center (TTC), Pueblo, Colorado. After 60 MGT of testing the JNR repair welds were rapidly wearing and were removed from service for metallurgical testing.

The primary objective of the test was to determine the gas-spray weld's ability to withstand the environment of 33,000 pound wheel loads. Its original development was for use on JNR's lighter axle load high speed lines.

The JNR and two TTC electric arc repair welds, which were made at the same time for comparison, were removed after 60 MGT. It was determined that the JNR weld wore at a rate of .050"/60 MGT while the TTC electric arc weld repairs demonstrated a wear rate of .035"/60 MGT. A .080-inch-deep simulated wheel burn defect was used for the repair test for both the JNR and TTC welds. A battered flash butt weld in the low rail of a 5-degree curve was also repaired with the JNR weld process. After 50 MGT, the original gas-spray build-up material was virtually worn away.

The weld repair tests were performed on a 5-degree curve and tangent track on the FAST loop under a 10,000-ton train with each car averaging 33 tons per axle. One weld of each type was made on the outside and inside rails on standard carbon rail. The gas-spray welds were made by a team of engineers from the JNR. The TTC welds, which were located a few feet from the JNR welds, were performed by site track welders.

The gas-spray process, which can be operated either semi or fully automatic, was designed partly to reduce operator inconsistencies that occur with manually operated welding practices.

Because of the lengthy heating time required to perform a JNR build-up weld, i.e., preheating and the actual build-up process, an extremely wide and soft heat affected zone (HAZ) was created in the rail. This is achieved by an oxyacetylene flame which spans the entire width of the railhead reaching a temperature of 2000 degrees Fahrenheit in the head of the rail. A large percentage of the normal pearlite lamellae microstructure was transformed into a softer spheroidized pearlite at the outer edges of the HAZ. This condition created high batter rates in the JNR welds because of the high percentage of spheroidized material in the HAZ. HAZ's in electric arc welds are kept at a minimum because of shorter welding times. Heat generated by electric arc sources are normally localized which result in narrow HAZ's and are normally contained to underneath the build-up deposit which protect them from exposure to wheel loads therefore, minimizing wheel batter.

A problem associated with electric arc weld build-up repairs is the concern of localized phase transformations due to fast cooling rates. Tests at the TTC have led to closely monitored preheating and postheat temperatures of the rail to make a successful weld. When these guidelines are closely followed, build-up welds using electric arc weld methods have shown a high success rate. When these guidelines are not closely followed, the chances of defective welds can be a potential problem.

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## 1.0 INTRODUCTION

Preserving a smooth running surface on the rail is an essential element of track maintenance. In order to maintain a smooth rail profile, it is frequently necessary to repair such defects as battered welds and engine wheel burns. Traditionally, electric-arc and flux core wire feed welding have been employed in the repair of these defects. Unfortunately, if the welding procedures are not followed, the long-term performance of the resulting welds has been less than satisfactory.

An alternative method of repair welding, called gas-spray welding, has been used by Japanese National Railway (JNR) in the repair of rail defects. In order to evaluate the utility of this technique, the Northeastern Corridor Division of Amtrack (NEC), in cooperation with the Federal Railroad Administration, funded a demonstration project. The gas-spray welding technique was applied to sites on the NEC and the Facility for Accelerated Service Testing (FAST) track at the Transportation Test Center (TTC), Pueblo, Colorado. To provide a basis for comparison, electric-arc and flux-core wire feed welds were also applied to sections of the FAST track. All test welds on the FAST track were then subjected to 60 million gross tons (MGT) of freight traffic during which periodic rail profile measurements were made. Upon completion of the 60 MGT of FAST traffic, the test welds were removed and analyzed for structural integrity using metallurgical techniques.

The remainder of this report describes test procedures applied at FAST and provides the results of metallurgical examinations of the gas-spray and electric-arc test welds.

## 2.0 TEST PROCEDURE

On the 4.8-mile FAST loop (Figure 1), three sites were selected for application of test welds using the gas-spray welding technique. The welds were performed by engineers from JNR. The sites are located in FAST test zones as follows:



# FAST

4.8 Mile Loop

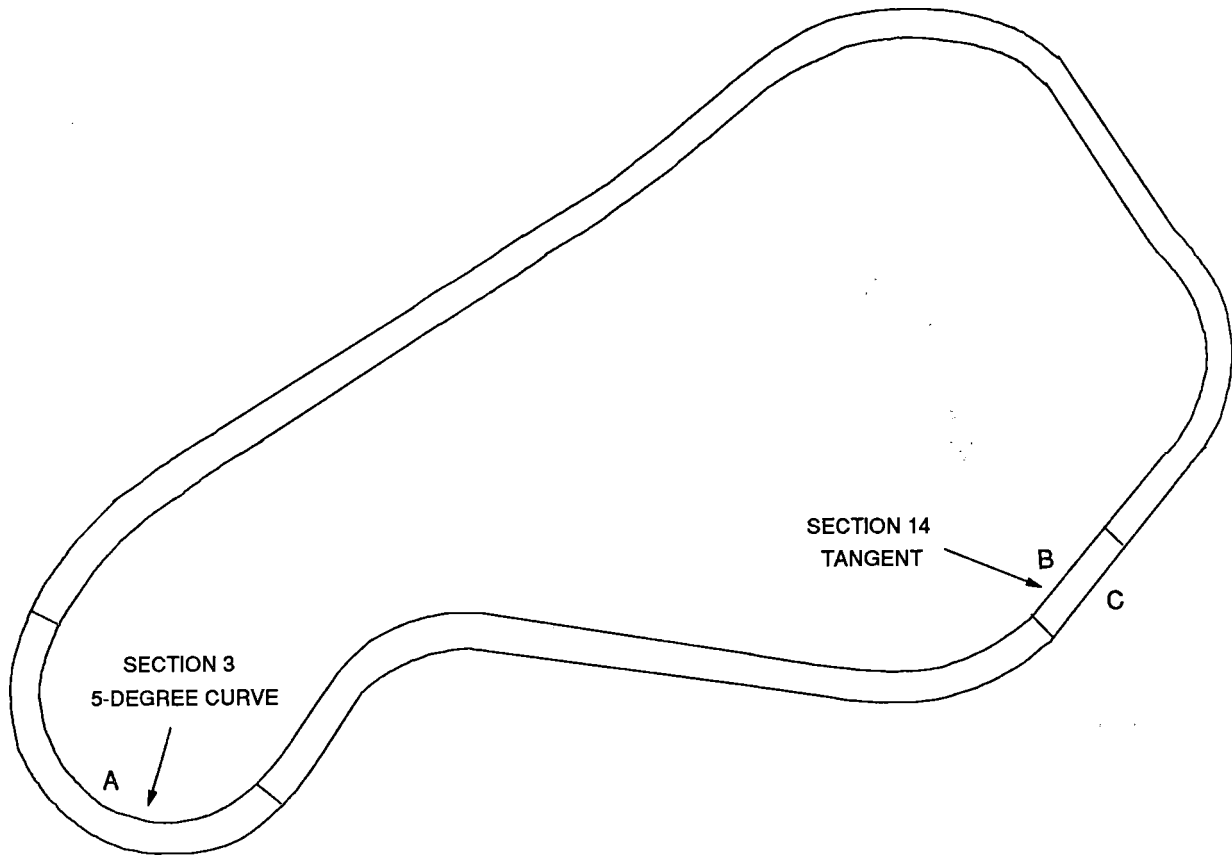


FIGURE 1. FAST TRACK WITH JNR GAS-SPRAY SITES

- Site A - Section 3, Tie No. 1133 (low rail of 5-degree curve)
- Sites B and C - Section 14, Tie No. 137 (tangent track)

In addition to the rail in the FAST track, two "control" welds were made for use in laboratory tests, including metallurgical evaluations.

## 2.1 THE WELDING PROCESS

The gas-spray weld build-up technique utilizes a fixture that guides flame from a torch head across a prescribed patch longitudinally along the railhead. Figures 2 through 8 show several stages in the weld build-up process. Appendix A is a document published by JNR. It details various stages for repairing an engine burn or battered weld.

The welding process is summarized in the following major steps:

- A. Site Preparation: The engine burn was ground away so that only non-heat-affected parent metal was exposed. Dye penetrant was applied to ensure that no microcracks were left in the parent metal-to-weld band interface.
- B. For the FAST demonstrations, the rail was unfastened for about 6 feet on each side of the weld site, and jacked about 2 inches high at the weld site. Shims held the rail in position to ensure that reverse bending during post-weld cooling would not result in a dip in the running surface. This step has since been eliminated as measurements made on rails out of track (136 lb test control rails) gave no indication of bending during the cooling stage.
- C. The welding fixture was then placed over the site and centered around the area to be built up (Figure 3).

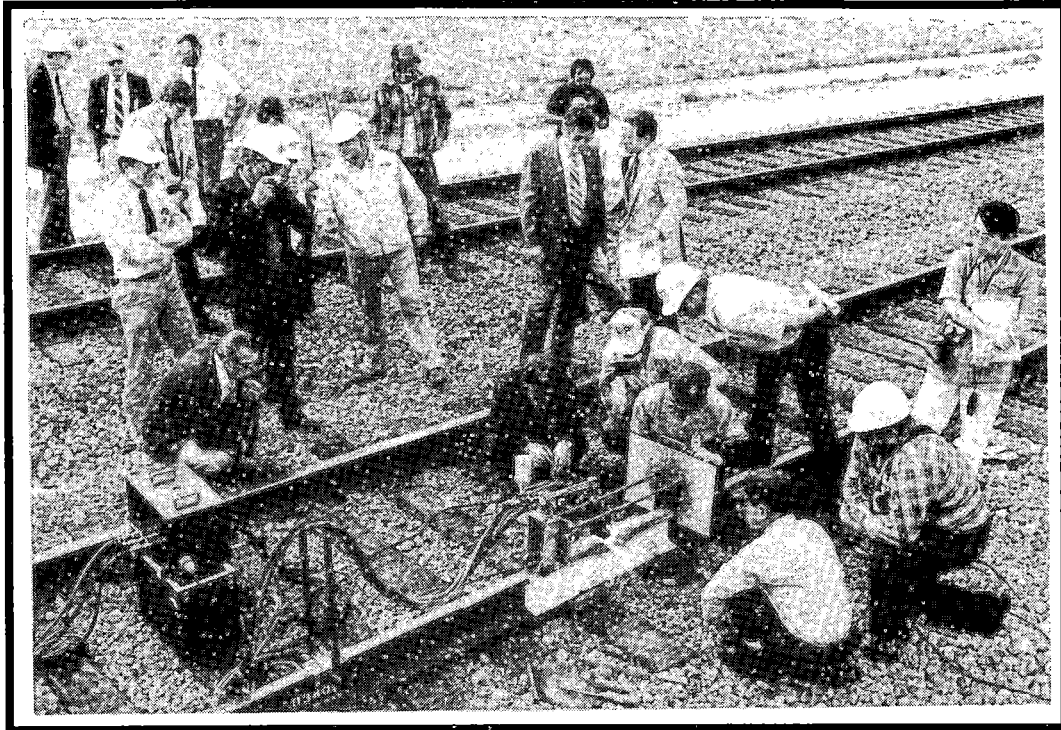


FIGURE 2. VIEW OF WELDING PROCESS

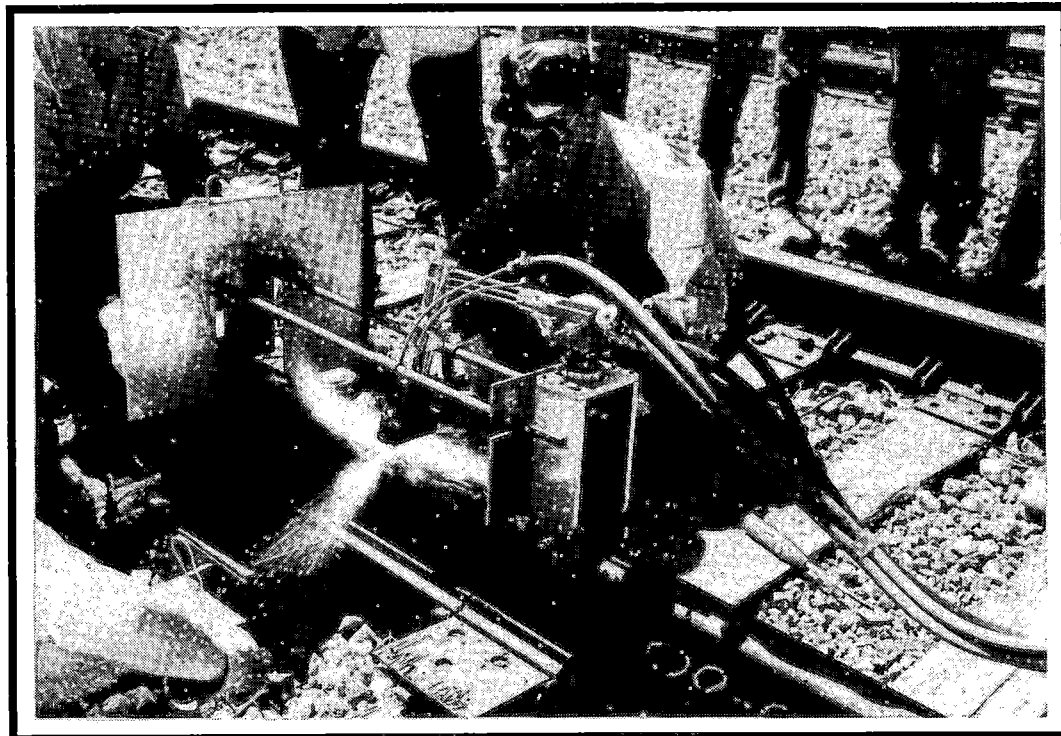


FIGURE 3. OVERALL VIEW OF WELDING PROCESS

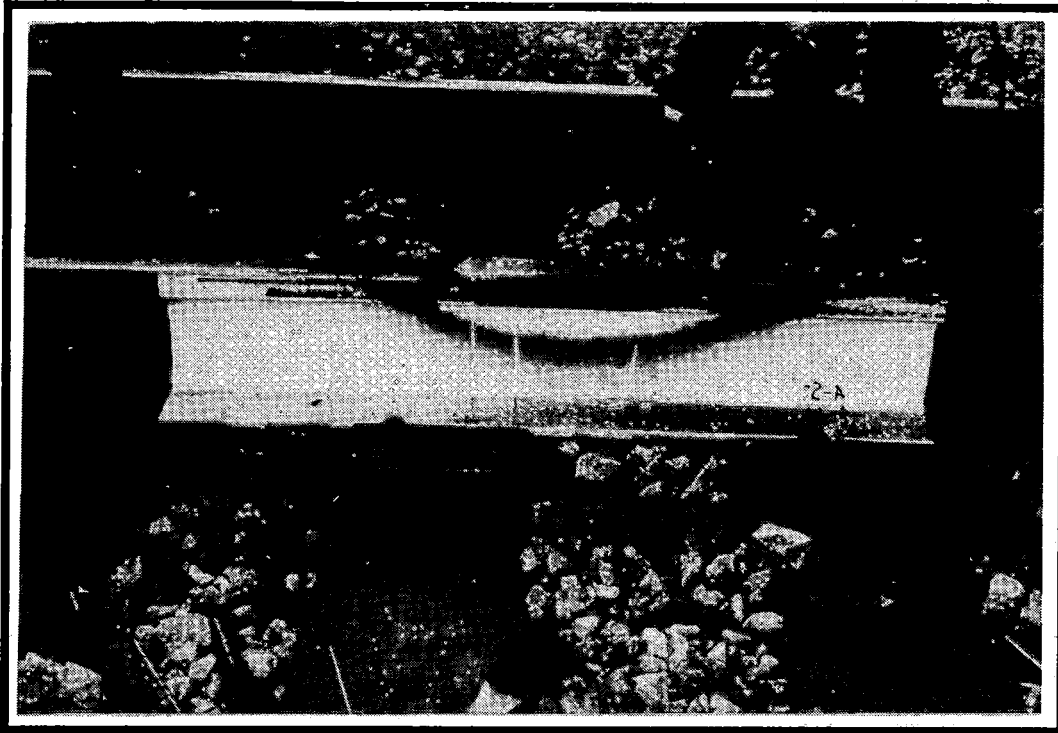


FIGURE 4. WELD REPAIR SITE AFTER BUILDUP, BEFORE GRINDING

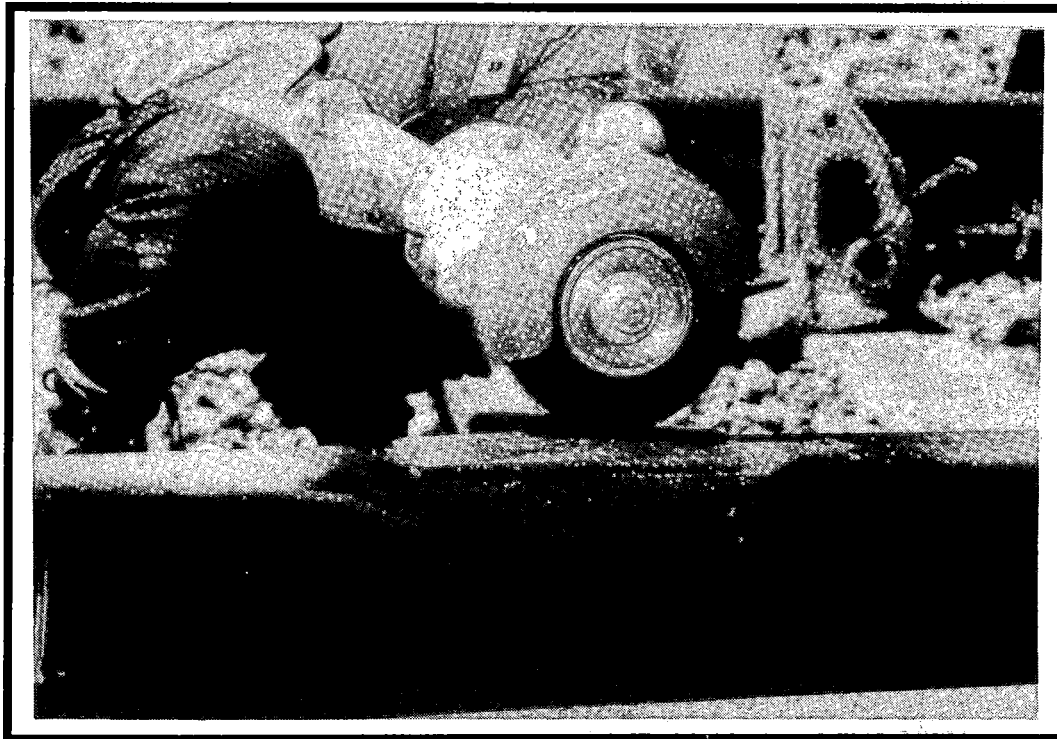


FIGURE 5. GRINDING OF REPAIR SITE

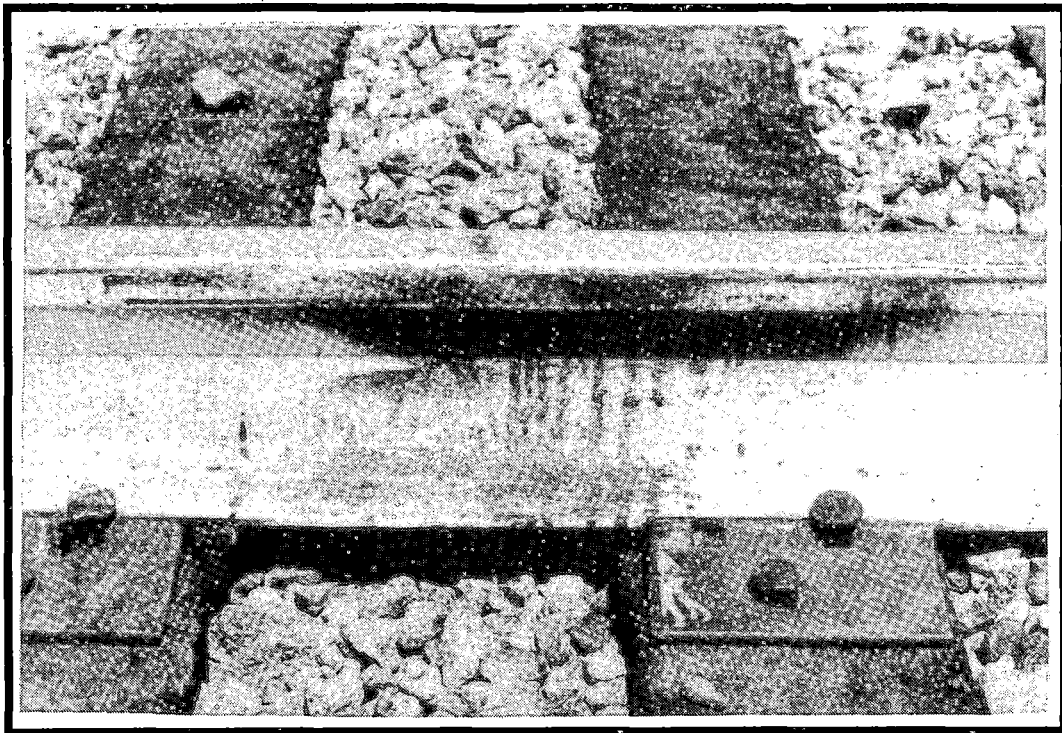


FIGURE 6. VIEW OF REPAIR SITE, AFTER GRINDING

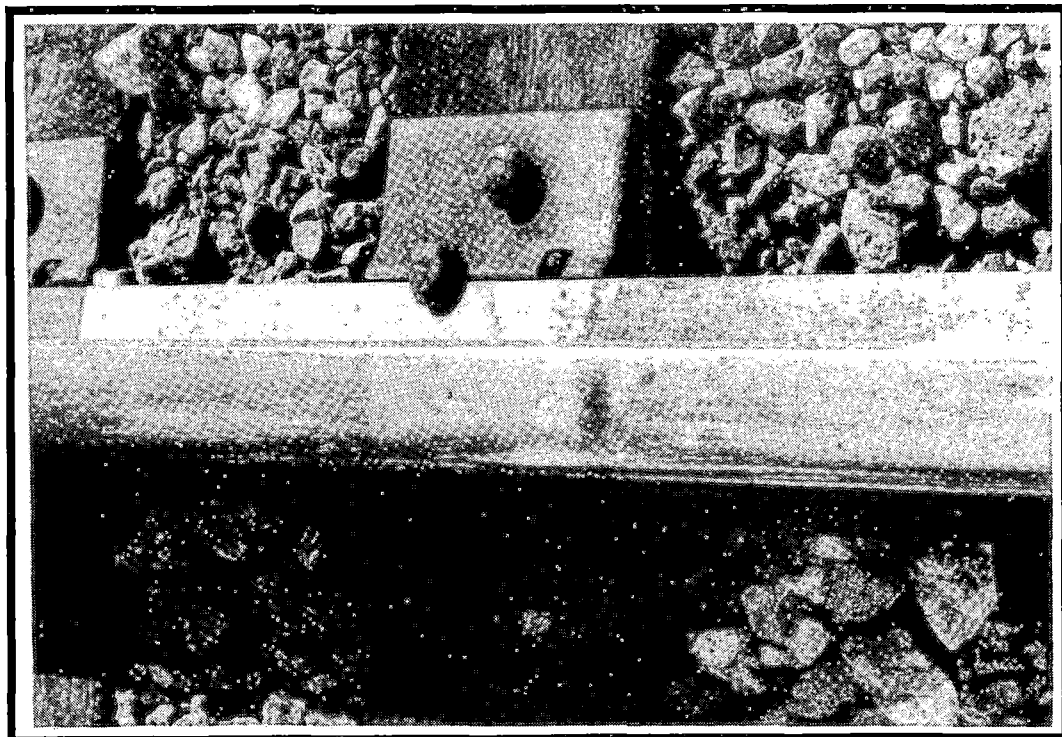


FIGURE 7. VIEW OF REPAIR SITE, AFTER GRINDING  
(NOTE KING BRINELL HARDNESS INDENTATION)

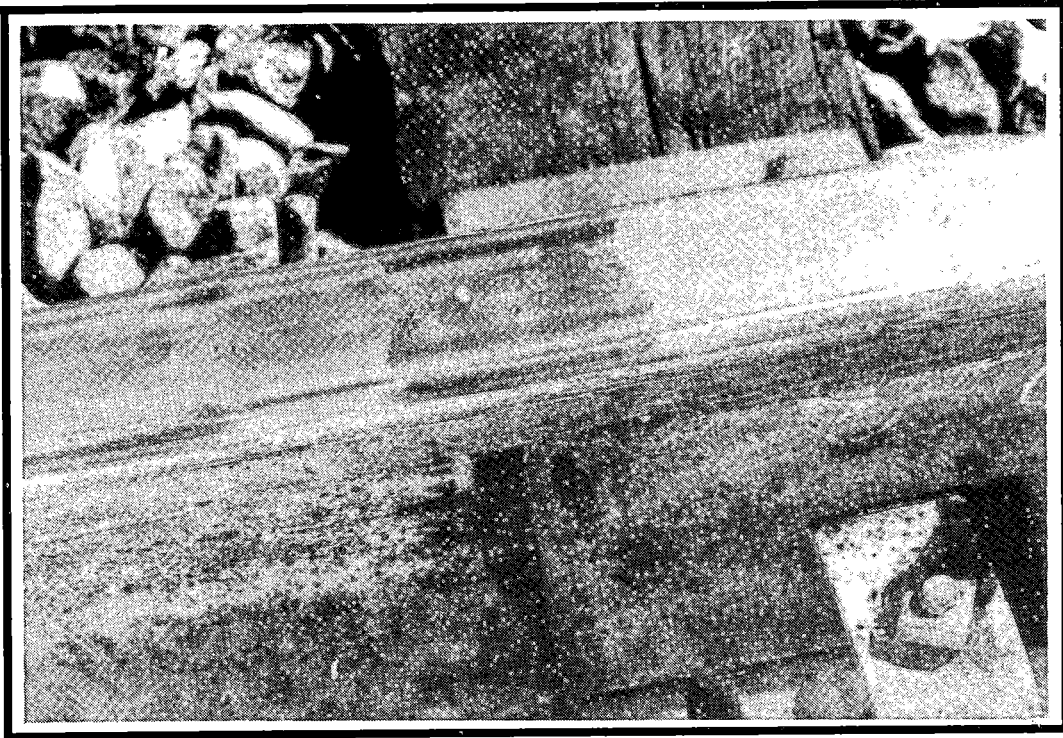


FIGURE 8. APPEARANCE OF SITE A, SECTION 3, SHOWING  
SECONDARY BATTER AT THE HEAT-AFFECTED ZONE

- D. The oxyacetylene torch was then ignited. The operator moved the torch head back and forth along the rails of the fixture. Several preheat passes were made prior to spraying any metal, resulting in a rail surface temperature of 500°F. The torch head was cooled by water recycled through hoses during this process. A second preheating period brought the rail up to 1,100°F.
- E. After a rail temperature of 2,000°F was reached, powdered metal was sprayed onto the rail surface using argon gas as a propellant. The argon gas also acts as a shield to prevent the metal particles from oxidizing.
- F. Subsequent passes were made to assure that sufficient metal was deposited so that no dip would be present after grinding. The rail was maintained at a temperature of 2,000°F by alternating passes with the oxyacetylene torch without application of metal.
- G. The built-up section was allowed to cool.
- H. The built-up section was then ground in a fashion similar to the conventional electric method, which is presently used by most U.S. railroads. Power grinders were used for the final grinding, followed by several finishing passes done with files by hand. This final finishing step (1) provides a finished surface so that surface defects may be readily detected, and (2) institutes a pride in workmanship -- the welders feel that they can take pride in their product.

I. In the FAST tests, the rail was then jacked down and refastened. (With the elimination of Step B, this step, too, is no longer required.)

J. Final site cleanup was then accomplished.

## 2.2 CONTROL WELD SITES

As a baseline control, two conventional TTC electric-arc build-up test welds were made soon after the JNR gas-spray welds. These welds were located on the same rails near the JNR welds. An additional electric-arc build-up was made for laboratory analysis.

Although conventional electric-arc tools were used, the welding technique used by the FAST track welders has very tight controls. The FAST environment allows for extensive quality control over work, along with track time required to complete the weld repair without being interrupted by train passage.

Appendix C lists the standard welding procedure used for the weld sites. The FAST track welders worked directly with the TTC metallurgist to ensure that proper preheating and postheating of all welding sites were obtained. This resulted in welding repair that has provided very satisfactory results, but at great expense in time and training.

Not all weld repairs with the revised "FAST method" have been totally successful. Observed life spans range from more than 100 MGT to as low as 10 MGT. It is essential that all preheating and postheating steps be followed to prevent the high risk that martensite or microcracks will develop at the bond surface. Exceptional track time is required -- more so than with conventional arc welding procedures.

## 2.3 DATA COLLECTION

The JNR gas-spray welding test at FAST consisted of two parts: the field demonstration, with three test welds subjected to over 60 MGT



of FAST traffic, and the laboratory analysis performed on a number of test welds made on out-of-track rails.

Data taken on the field samples were as follows:

1. Longitudinal running surface profile (LRP) over an approximate 3-foot length.
2. Brinell hardness along the running surface at several locations.
3. Surface hardness along the surface at several locations, using the Shore Hardness Tester.

The field test was in place for approximately 60 MGT of traffic. Then one rail (Section 14, Tie No. 337) was removed for laboratory analysis.

The two field electric-arc repair sites were subjected to the same traffic and set of measurements. Appendix B contains the laboratory analysis results from these welds.

### 3.0 DISCUSSION AND RESULTS

#### 3.1 JNR GAS-SPRAY WELD

Although the FeNiCr-based self-fluxing JNR alloy powders exhibited favorable mechanical properties in laboratory tests, their ability to withstand severe service wear and metal flow in heavy tonnage traffic was limited to 60 MGT in tangent track under FAST conditions. A similar JNR gas-spray build-up weld was used to repair a battered flash butt weld in the low rail of a 5-degree curve in Section 3 of FAST. The repair depth at this site was less than that of the tangent. After 50 MGT, it began to wear rapidly; and at 60 MGT, no sign of the original gas-spray build-up repair weld could be found. It should be noted that the FAST train was made up almost entirely of loaded 100-ton hopper cars (33-ton axle loads), with each train pass applying about 10,000 tons of traffic.

The .080 inches of build-up material on the tangent track site provided a wear rate of about .050 inches/60 MGT, which was somewhat higher than the parent metal head height wear rate.

Because of the wide heat-affected zone (HAZ), which appears in the JNR weld, the secondary batter will cause uneven surface geometry. The batter in the HAZ is clearly visible in the LRP charts in Figure B-7. Because of the high temperatures that were obtained with the JNR process, the build-up of head hardened rails is not recommended. These high temperatures would be detrimental to the head hardened structure, resulting in a loss of hardness, thus adding to the batter.

Slow cooling of the repair area is part of the gas-spray process, and chances of localized phase transformation (martensite development) are less likely to occur.

The gas-spray repair site maintained its running surface with no spalling or other mechanical failure during the entire 60 MGT period. Some metal flow was detected after 60 MGT.

The TTC/FAST gas-spray test utilized only one of several available powdered metal alloys. Other alloys are available which could offer a harder and more wear-resistant running surface that is more suitable to heavy tonnage. Also, as the primary purpose of this test was to evaluate basic weld repair life, no production rail surface grinding was performed over these rails during the life of the test.

### **3.2 TTC ELECTRIC STICK ARC WELD**

At 60 MGT, the TTC weld exhibited adequate resistance to wear displaying a batter rate of .035 inches/60 MGT. Metal flow on tangent track was minimal, but showed signs of some batter in the weld build-up region.

Narrow HAZ's in the electric-arc weld repair prevented secondary batter in the region adjacent to the weld deposit.

Because of the tempered martensitic structure of the electric-arc electrodes and the deep penetrating qualities of an electric-arc, the TTC build-up accumulated very little wear as compared to that of the JNR build-up repair which can be seen in Figure B-11.

Revised welding procedures at the TTC have minimized micro-cracking and martensite formation usually associated with arc welding.

#### 4.0 CONCLUSIONS

The JNR gas-spray method for engine burn repair performed without failure for the 60 MGT duration of the FAST test. There were no surface defects, such as spalls, chips or breakouts. The relatively large HAZ developed some rail batter, which may have increased to an unacceptable depth had the test been operated for a significantly longer period. Wear rate of the material used in the gas-spray repair sites was somewhat higher than that of the standard carbon rail used at these sites.

A conventional electric-arc repair method, installed at the same time, exhibited similar characteristics as the gas-spray method, with somewhat less rail batter due to less distributed heat input into the welding repair process. Signs of batter from the HAZ were not apparent because the HAZ in electric-arc build-ups remains underneath the built-up material (see Figure 13-10). It should be noted that the "conventional" electric-arc method is normally used at the TTC and involves considerable control and care by the welding crew. Detailed preheat and interpass temperatures are carefully maintained to provide this control, and many of these steps are not followed by welding crews working in typical railroad field conditions. The detailed control of heating and cooling results in a minimum amount of surface and subsurface cracks normally associated with electric-arc repair methods. This control is possible at the TTC as track time for installation of test methods can be scheduled.

The JNR gas-spray method provides an acceptable alternative to the standard electric-arc method. Investigation into a harder metal that may wear longer should be made, as repairs on rail harder than the standard rail used in this test (such as head hardened rail) may lead to increased batter of the repair site.

The electric-arc method, as used by the TTC, does provide an acceptable repair, but it is essential that all quality control steps be carefully followed.

APPENDIX A

REPORT ON

RECLAMATION OF RAILS BY GAS-SPRAY WELDING IN JAPAN

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RECLAMATION OF RAILS BY GAS-SPRAY  
WELDING IN JAPAN

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# RECLAMATION OF RAILS BY GAS-SPRAY WELDING IN JAPAN

## Abstract

A partial damage or wear on a rail running surface, for example, engine burn, rail end batter and welded rail end batter etc, often occurs in service. The rail with such local damages or wears had been renewed in principle. As one of the countermeasures for the repair of the rail, we have developed the oxyacetylene gas-spray welding method using the newly developed self-fluxing alloy powder (Fe-Ni-Cr).

Through our five years experience in the field, this technique has been proven to be very successful and has been put to practical use for engine burns of continuous welded rail since 1982 in JNR.

A few of the characteristics is as follows.

1. Low heat input and no liquefying the parent metal (rail). Consequently this method is able to prevent the growth of minute cracks in the parent metal adjacent to weld interface (liquation crack).
2. Compact and light equipments.
3. High operation efficiency because of use of the special wide spraying torch fitting to rail head width.

Though the time required for the entire procedures varies according to size of engine burn, it generally takes less than an hour in the field (welding time: about 20 minutes).

This paper deals with the outline of the gas spray welding, equipments, materials, procedures and qualities of build up welds (microscopic structure, hardness distribution, bending and rolling load fatigue test etc) and, furthermore, the results of the application to engine burns and rail end batters in the field.

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## 1. Introduction

It is well known that a rail often has local damage generated on the tread surface thereof during use such as engine burn, skid, corrugation, local wear at weld of a continuous welded rail and rail end batter, as well as breakage and fracture. It is highly desired to develop techniques of rapidly and effectively repairing a rail having such local damage as the transport capacity of a railway is increased. More particularly, the increase in speed of a train causes the wide variation in wheel load due to unevenness of the damaged portion of a rail. This causes a serious problem on an environmental disruption such as generation of noise as well as highly adversely affects a rolling stock and a track. Such a damaged rail has been conventionally repaired by removing the damaged rail portion and replacing it with a new rail. However, such exchange operation of a rail is difficult to take place because it is restricted by time in the existing circumstances that a time space is substantially shortened due to the increase in operating density of trains.

There have been conventionally used two kinds of method of repairing the damaged portion of a rail in the site where it is laid. One is to grind the damaged portion of a rail and the adjacent wholesome portion in an arcuate shape in view of the degree of damage. This method is relatively readily applicable by using an appropriate operating machine, however, the application is limited depending upon the degree of damage. This method is only effective to repair highly slight damage. The other method is to apply building-up to the damaged portion of a rail and then carry out finishing to allow the build-up to have a smooth surface. This method is applicable to a seriously damaged rail as well and will be the most desirable repairing method at the present if the quality of build-up of a rail can be effectively ensured.

In Japan, building-up of a rail was once extensively carried out by gas welding with a welding rod for filler metal such as TEKKEN GI<sup>1)</sup> developed in the latter half of

the 1940's and the like. Thereafter, building-up by arc welding with covered electrode took place in an experimental scale. However, such welding methods had a disadvantage of causing flow of building-up metal, peeling thereof and the like in cooperation with materials employed at that time. Thus, the build-up welding of a rail was hardly carried out with few exceptions.

In foreign countries, build-up welding of a rail has been positively carried out mainly by arc welding with a covered electrode.<sup>2)3)</sup> Besides, build-up welding has been also reported which is carried out by automatic CO<sub>2</sub> arc welding,<sup>4)</sup> semi-automatic arc welding with flux cored wire,<sup>5)~8)</sup> spraying using oxy-acetylene flame<sup>9)</sup> or the like.

When arc welding is applied to high carbon steel, it is required to take full care to prevent hot crack from being generated at the weld bond, because even fine hot crack often causes fatigue fracture. Results<sup>2)</sup> of a rolling load fatigue test on built-up rails formed by gas welding and arc welding with covered electrode clearly show that the fatigue strength of the built-up rail by the latter welding is lower than that by the former welding due to such a weld flaw as mentioned above. In order to reduce hot crack, it is first required to highly decrease welding heat input.

However, the decrease in welding heat input generally causes the operation efficiency to be decreased. The operation of building-up a rail is carried out in the site in the intervals of a train service, thus, extension of the operating time is fatal to the build-up welding. Also, in Japan there is not provided a sufficient space around a track, thus, it is substantially difficult to carry a weighty apparatus such as a power source device in the track. This requires the miniaturization and weight-saving of a build-up welding apparatus.

In view of the foregoing problems, the authors have considered the application of gas-spray welding with self-fluxing alloy powder to the building-up of a rail which is supposed to be a welding method capable of effectively decreasing heat affection with respect to matrix, improving

operating efficiency and accomplishing building-up using a compact apparatus.

## 2. Summary of Gas-Spray Welding with Self-Fluxing Alloy Powder

The spraying of metal or the like generally has an advantage that it does not substantially give material to be sprayed any heat affection and cause spraying material to be fused to matrix, to thereby be widely used for corrosion protection, building-up and the like. However, the bond strength obtained by spray welding is much low as compared with that by build-up welding. Besides, spray welding with self-fluxing alloy allows the mechanical properties of an article welded by spraying to be highly improved by subjecting the weld of the article to a melting treatment after or concurrently with the spraying. Also, the spray welding has further advantages that it does not cause the fusion of spray-welding material to the matrix of welded material, heat affection with respect to welded material is relatively little, and welded material can be formed with a build-up which has a smooth surface and large thickness. Self-fluxing alloy, as shown in Table 1, is super alloy of Ni base, Ni-Cr base, Co base or the like which contains about 1.5 to 3% of B and about 2 to 4% of Si. When this alloy is re-melted after spraying, B and Si react with metal oxide included in a build-up to form boron-silicate glass slag of a low melting point, which is floated on the surface thereof, thus, the build-up is rendered highly clean. This treatment also allows building-up metal and the matrix of built-up metal to diffuse into each other to form a firm weld. Generally, self-fluxing alloy is in the form of a powder or a rod. Powdered self-fluxing alloy is used for spray welding and rod-shaped one is widely used as a filler metal to provide a glass mold, a sleeve, a roll shaft and the like with heat resistance, wear resistance, corrosion resistance and the like. Spray welding with self-fluxing alloy is generally carried out using an oxy-acetylene flame. In a specific case, it often takes place

using an oxy-hydrogen flame or plasma jet. Self-fluxing alloy generally exhibits an excellent property against compressive stress, however, it is relatively fragile under tensile stress and is poor in ductility and toughness. For example, Ni base and Co base self-fluxing alloys are about 30~40 kgf/mm<sup>2</sup> in tensile strength and have an elongation of about 1% or less. A rail for railway line is made of high carbon steel. The mechanical properties of the rail, which are somewhat different depending upon the type of rail, are defined to have a tensile strength of 80 kgf/mm<sup>2</sup> or more and an elongation of 8% or more in a tensile test using JIS No. 4 specimen prepared according to JIS Z: 2201-56. Conventional self-fluxing alloy has wear resistance and workability sufficient to be used for build-up welding of a rail, however, it is required to substantially improve the tensile strength and toughness.

Table 1 Typical Chemical Composition of Self-Fluxing Alloy

| Type          | Ni  | Cr | Co  | B   | Si  | C   | W | Wc | Fe  | H.Rc  |
|---------------|-----|----|-----|-----|-----|-----|---|----|-----|-------|
| Ni-B-Si       | Bal | -  | -   | 1.9 | 3.5 | -   | - | -  | 2.5 | 25-35 |
| Ni-Cr-B-Si    | Bal | 10 | -   | 1.8 | 3.5 | 0.4 | - | -  | 2.5 | 27-35 |
| Ni-Cr-B-Si    | Bal | 11 | -   | 2.0 | 3.0 | 0.5 | - | -  | 3.5 | 35-40 |
| Ni-Cr-B-Si    | Bal | 13 | -   | 2.2 | 3.0 | 0.6 | - | -  | 3.5 | 40-45 |
| Ni-Cr-B-Si    | Bal | 15 | -   | 2.4 | 3.5 | 0.8 | - | -  | 3.5 | 45-50 |
| Ni-Cr-B-Si    | Bal | 16 | -   | 3.0 | 3.5 | 1.0 | - | -  | 3.5 | 55-60 |
| Co-Cr-B-Si    | -   | 22 | Bal | 2.6 | 3.0 | 1.0 | 6 | -  | 2.5 | 54-60 |
| Co-Cr-B-Si    | -   | 19 | Bal | 2.2 | 2.0 | 0.1 | 3 | -  | 2.5 | 43-48 |
| Ni-Cr-Wc-B-Si | Bal | 12 | -   | 2.5 | 3.5 | 1.1 | - | 15 | 2.5 | 57-64 |
| Ni-Cr-Wc-B-Si | Bal | 10 | -   | 2.4 | 3.5 | 1.7 | - | 28 | 2.5 | 60-65 |

### 3. Material and Apparatus for Gas-Spray Welding

#### 3.1 Self-Fluxing Alloy for Spray Welding of Rail

Self-fluxing alloy powder is required to have satisfactory mechanical properties and adhesion to a rail,

hardness similar to that of the matrix of a rail, good wear resistance, good workability, and a low melting point sufficient to minimize heat affection with respect to the matrix.

### 3.1.1. Trial Manufacture of Ferroalloy Powder (F-3)

First, for the purpose of improving strength, alloy powders were experimentally prepared using Ni-Cr base alloy of a relatively low melting point as a base and varying the content of Ni, Cr and Fe, and formed into cast alloys. The cast alloys were subjected to a tensile test. The contents of B and Si were minimized to the extent that good workability is ensured (B: 1.5%, Si: 2.0%). The tensile test clearly showed the fact that high strength is obtained at the content of Ni of 30 to 40% and elongation is hardly affected by the content of Ni, and tensile strength and elongation are somewhat increased with the increase in content of Cr in the range of Ni content described above. In view of such fact, ferroalloy (F-3) was experimentally prepared which has chemical compositions shown in Table 2. Table 2 also shows the mechanical properties of the ferroalloy and commercially available Ni-Cr base alloy. From the table, it will be noted that F-3 has relatively high tensile strength.

Self-fluxing alloy generally exhibits satisfactory wear resistance. For the purpose of comparing the wear resistance of the experimentally prepared ferroalloy (F-3) with that of commercially available or conventional self-fluxing alloy, F-3 was subjected to a wearing test together with the conventional alloy. In this test, alloys V3 and V4 shown in Table 2 were used as a comparison material. The test piece or specimen was formed into such a shape as shown in Fig. 1. The specimen was sampled from cast material, and tire steel was chosen as the opponent material in view of the use conditions of a rail. The test was conducted in the form of rotation wear in a dry atmosphere with load and slip factor being respectively set at 92kg and 2.6%. Fig. 2 shows measurements of wear loss at

various rotating numbers under the above conditions. As can be seen from Fig. 2, F-3 clearly exhibits excellent wear resistance as compared with the conventional alloy.

Table 2. Chemical Composition and Mechanical Properties of Trial Ferroalloy(F-3) and Ni-Cr Alloy

| Type | Chemical composition(%) |      |     |     |     |     | Mechanical properties                   |                |
|------|-------------------------|------|-----|-----|-----|-----|---|----------------|
|      | Ni                      | Cr   | Fe  | B   | Si  | C   | Tensile strength (Kgf/mm <sup>2</sup> ) | Elongation (%) |
| F-3  | 37.0                    | 13.0 | Bal | 1.5 | 2.0 | 0.2 | 60~70                                   | 1.2~2.2        |
| V-4  | Bal                     | 10.0 | 2.5 | 1.9 | 3.0 | 0.3 | 32~40                                   | 0.3~1.0        |
| V-3  | Bal                     | 9.0  | 3.5 | 1.6 | 2.5 | 0.1 | 25~35                                   | 0.4~1.2        |

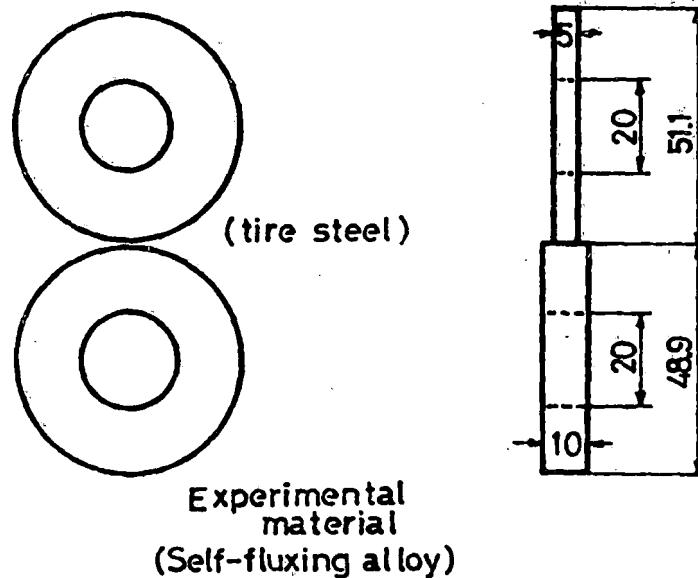


Fig.1 Test Pieces for Rotation Wear Test

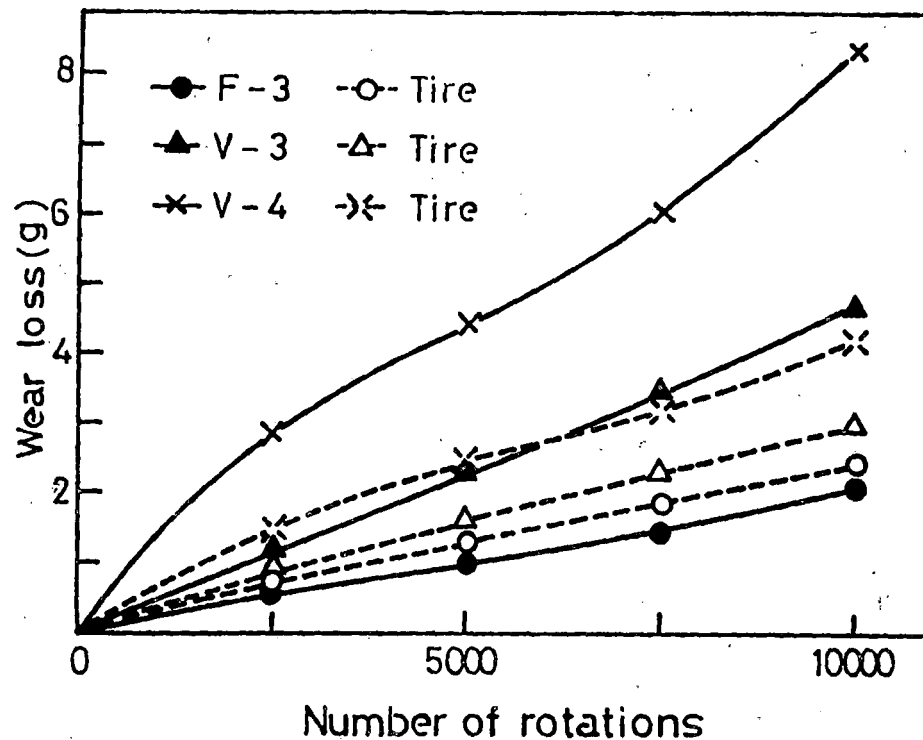


Fig.2 Relation between Wear Loss and Number of Rotations

3.1.2. Mechanical Properties of Build-Up of Rail with F-3

In view of the use conditions for a built-up rail, a strength test of a build-up was carried out using specimens prepared by subjecting a plate and a rod sampled from a rail to gas-spray welding. The test includes a cross-tension test, a shearing test, a shearing fatigue test and a wearing test.

(a) Cross-tension and shearing tests

In cross-tension and shearing tests, a build-up was regarded as a spot weld and formed to have configurations and dimensions shown in Fig. 3. An object of the tests is to measure bond strength between welding material and a rail; thus, a specimen used comprises an upper mild steel plate and a lower rail steel plate and build-up welding was applied to a through-hole of the upper plate to carry out welding with respect to the lower plate, using a commercially available single-nozzle spraying torch. The specimen was prepared according to the following conditions:

Powder: F-3, 100 to 400 mesh

Surface treatment of lower plate (rail steel): grinding

Distance between spraying torch and upper plate: 15.5mm

Gas flow rate:  $C_2H_2$  --- 8.0 l/min,  $O_2$  --- 10.0 l/min

Pre-spraying: yes and no

"Yes" was carried out at a rail steel plate temperature of about 400°C for 3 seconds.

Spraying time: 14 seconds

Temperature of building-up:

Tension test specimen --- 1000 ~ 1140°C

Shearing test specimen --- 900 ~ 1280°C

The temperature of a build-up was measured at a position of 1mm below the surface of the lower plate. The tests were carried out using 30 ton Amsler universal testing machine. In general, there occurs a problem that in a shearing test of a sheet, the component of tensile stress is added to shearing stress due to the deformation of a specimen; whereas a tensile test thereof causes the deformation of a specimen in a direction of tearing a build-up, so that shearing stress which is to cause the periphery of the build-up to be subjected to fracture is complicatedly added to tensile stress. However, the present tests did not cause the specimen to be highly deformed because the upper plate of the specimen is relatively large in thickness and the matrix of the lower plate has high strength. Fig. 4 shows relationships between shearing and tensile strengths and a building-up temperature. For comparison, Fig. 4 also shows as-welded strength of a spot weld of 50 kgf class high strength steel (spot welding conditions: welding pressure of electrode --- 900kg, welding current --- 14500A, weld time --- 54 c/s).<sup>10)</sup> Fig. 4 indicates that shearing strength increases with the increase in temperature, reaches the maximum strength at a certain temperature and then gradually decreases. Also, it will be noted that the tensile strength is at the substantially same level as that of the spot welding of 50 kgf class high strength steel irrespective of



the pre-spraying within a temperature range of 1000 to 1100°C.

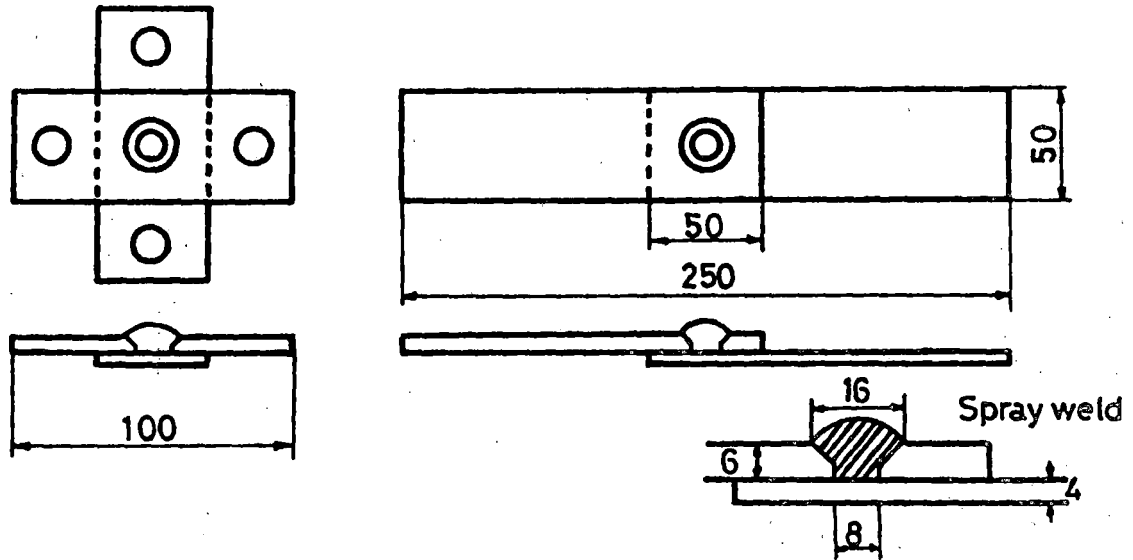


Fig.3 Test Pieces for Cross Tension and Shearing Test

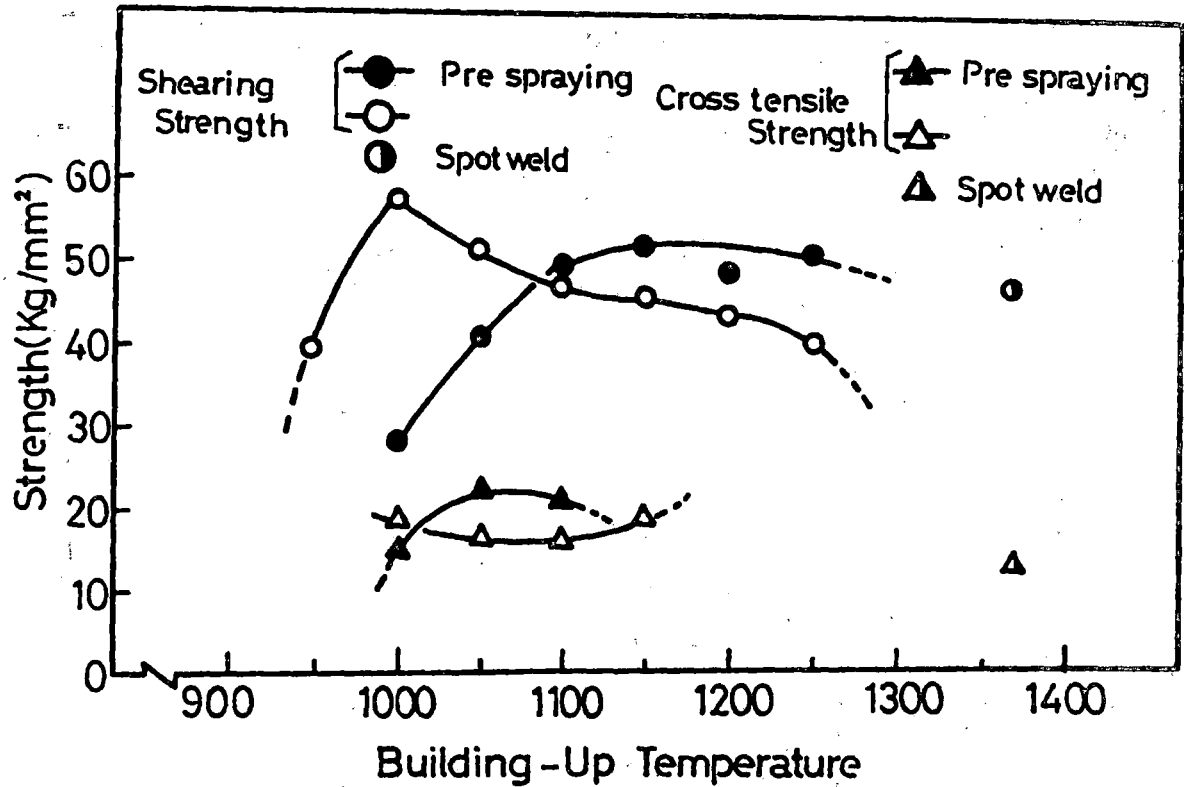


Fig.4 Relation between Both Shearing and Tensile Strength and Building-Up Temperature

(b) Shearing fatigue test

A shearing fatigue test of a build-up was carried out at a loading cycle of sine wave form and a repetition rate of 500 cycles/min using a fatigue test machine as shown in Fig. 5 and the same specimen as in the above-mentioned shearing test. Fig. 6 shows results of a shearing fatigue test using a specimen subjected to build-up welding at a temperature of 1000 to 1140°C. For comparison, results obtained using a specimen of 50 kgf class high strength steel of which a spot welding was subjected to a tempering treatment are also shown in Fig. 6. The results of Fig. 6 clearly show that the specimen subjected to building-up at a relatively low temperature has a repetition rate exceeding  $10^7$  cycles/min under high load. Thus, it appears that the state of bonded interface of the build-up substantially affects the fatigue test, as in the shearing test. However, as is clear from the results of Fig. 6, the build-up formed by gas-spray welding has considerably satisfactory shearing fatigue strength as a whole.

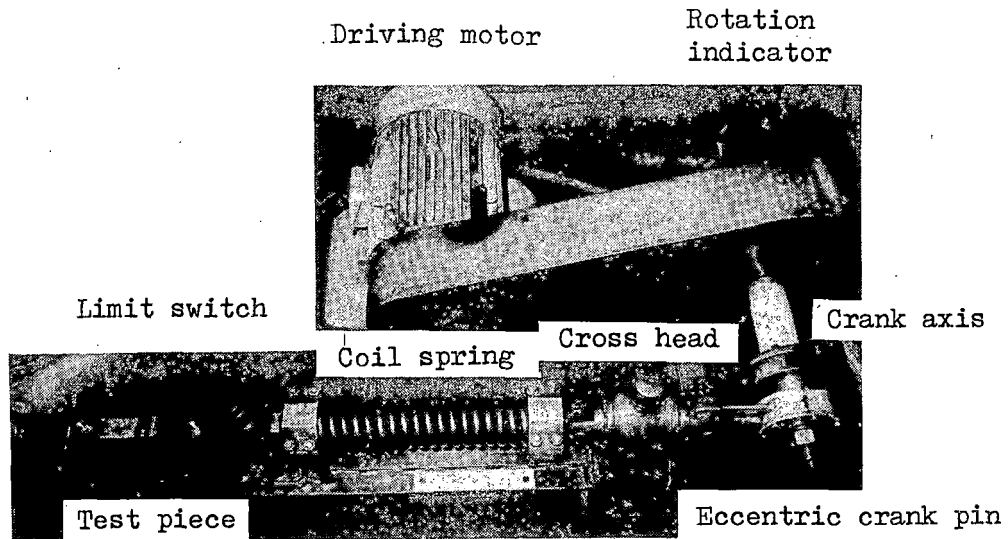


Fig.5 Shear Fatigue Machine

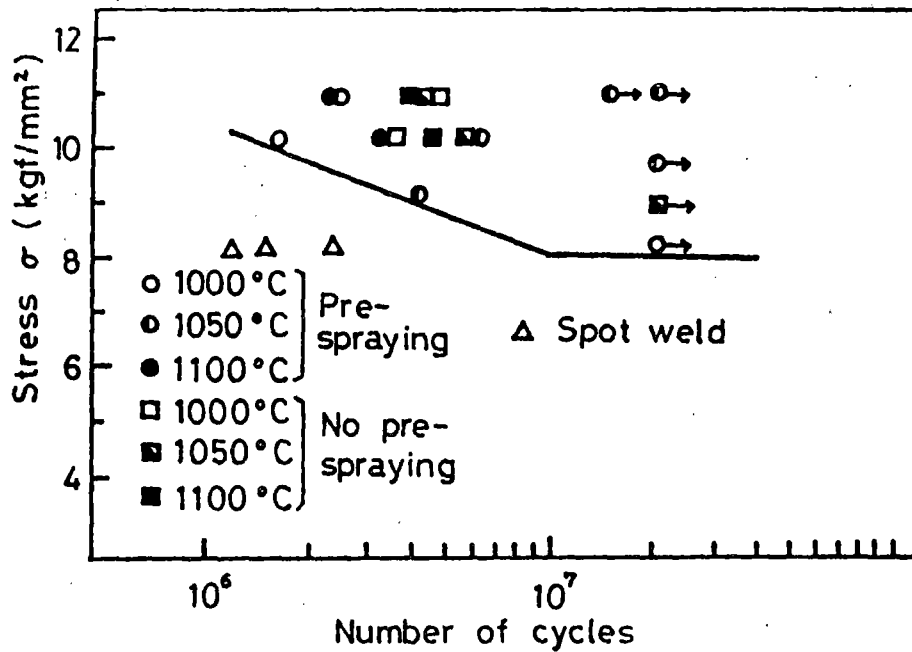


Fig.6 S-N Diagram in Shearing Fatigue Test of Gas Spray Weld

(c) Wearing test

Gas-spray welding was applied to the smooth surface of a piece sampled from a rail steel and formed in a shape shown in Fig. 7 in a manner as shown therein, and a wearing specimen was sampled from the central portion of the piece and subjected to a rolling wearing test including a slip. The configuration and dimensions of specimen and the manner of test were the same as in Item 3.1 described above. Gas-spray welding was carried out under the following conditions:

Matrix: Rail steel

Surface treatment of matrix: Grinding

Gas flow rate:

$C_2H_2$  --- 5.7 l/min,  $O_2$  --- 6.0 l/min (Spraying)

$C_2H_2$  --- 6.5 l/min,  $O_2$  --- 6.0 l/min (Pre-heating)

Distance between nozzle and matrix:

12mm (Spraying torch)

15mm (Pre-heating burner)

Building-up speed: 23 mm/min

Building-up temperature: 1000 ~ 1150°C

Fig. 8 shows a relationship between the rotating number of each specimen and wear loss. Fig. 8 indicates that the wear loss reaches the maximum value at 1150°C which is the highest building-up temperature, and decreases in the order of 1080°C and 1000°C. However, the term "wear loss" referred to herein does not indicate the wear loss of only a build-up but indicates the wear loss of a specimen including the matrix, thus, it is largely occupied by the wear loss of matrix. Thus, it is supposed that the difference in wear loss indicates the difference in heat affection (softening) on the matrix due to the difference in conditions for spray welding. Also, the phenomenon that the build-up highly wears as compared with the matrix does not occur. The conditions for the present test are considerably severer than the actual use conditions, therefore, there will be a possibility that the peeling and breaking of a build-up occur in certain circumstances. Fig. 9 is a microstructure of the build-up of a specimen of which the number of rotations exceeded ten thousand. As is clear from Fig. 9, there is shown no occurrence of peeling in each specimen. Particularly, there is no defect in the end or periphery of the build-up which often tends to cause any weld defect due to the unstable spraying, and the end of the build-up gets intimate with the flow of the matrix.

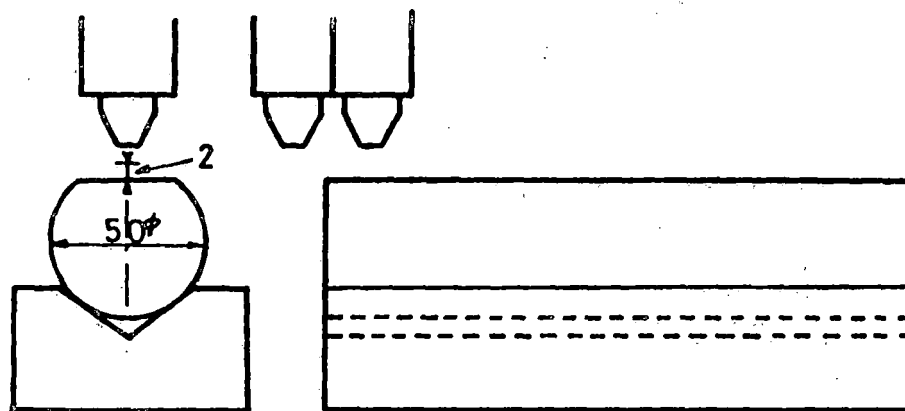


Fig.7 Spray Welding Procedure to Test Piece for Wearing Test

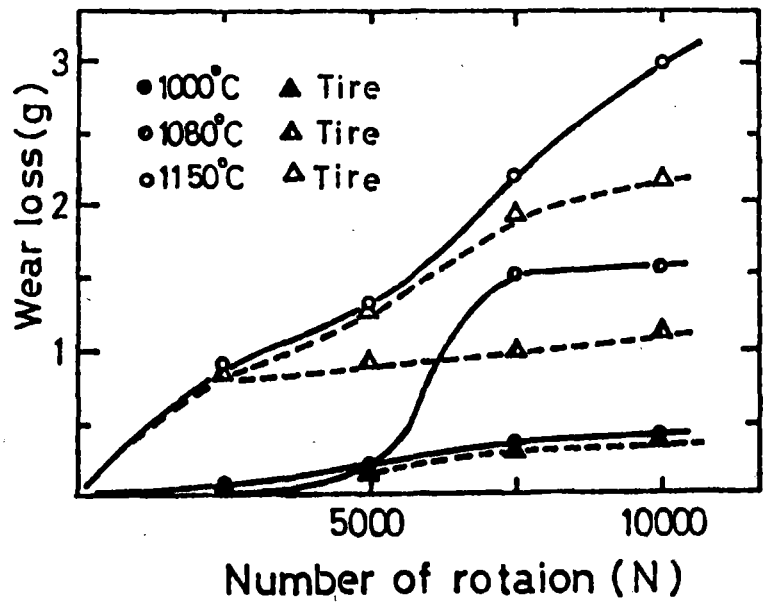
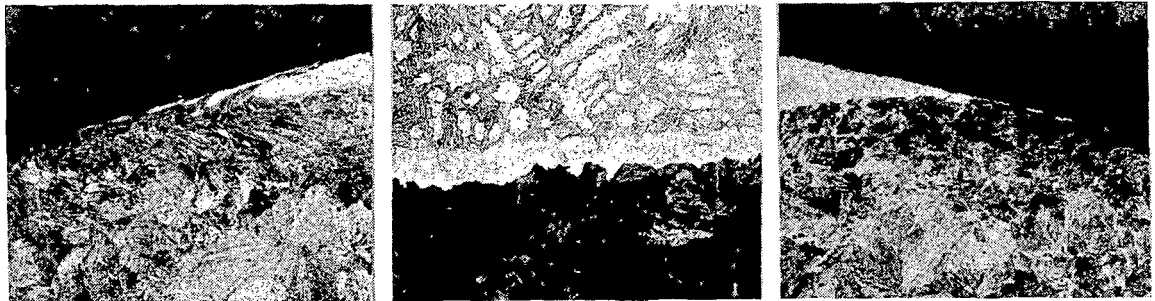


Fig.8 Relation between Wear Loss and Number of Rotations



NO. 1

NO. 2

NO. 3

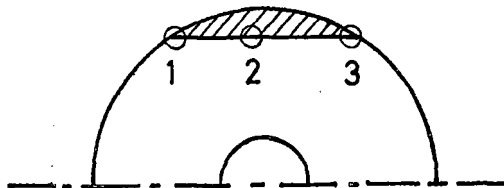


Fig.9 Microstructures of Spray Weld after the Number of Rotations Reaches 10000

### 3.1.3. Improvement in Self-Fluxing Alloy F-3

F-3, as described in Item 3.1.2. mentioned above, has high strength and elongation, as compared with commercially available Ni-base and Co-base self-fluxing alloys. However, in order to put it into practical use, it is desired to further improve the ductility. The lack of ductility is partially or mainly caused by B and Si which are added to the alloy to provide the alloy with a self-fluxing property. In view of this respect, the influence of B or Si of which the content is previously limited to a low level as compared with the conventional self-fluxing alloy and also that of other minor elements were considered by carrying out a tensile test in the substantially same manner as in Item 3.1.2. Fig. 10 shows an influence which the content of B in F-3 has on tensile strength and elongation of F-3. Fig. 10 clearly indicates that the elongation is increased by 5~6% at the content of B between 0% and 0.8% and the tensile strength is decreased with the decrease in content of B. Whereas, Si does not substantially affect the tensile strength and elongation at the content between 0% and 2%. Fig. 11 shows an influence of Mo on the improved F-3 having the content of B decreased to 0.5% in view of the above test results. The tensile strength is substantially improved at the content of Mo up to 10% (60 to 70 kgf/mm<sup>2</sup>) and decreased when the content exceeds 10%. Elongation of the improved F-3 is expected to be increased by 6 to 7% at the content of Mo up to about 5%. Thus, it will be readily understood that F-3 self-fluxing alloy of considerably satisfactory strength and elongation and having an impact value substantially equal to that of matrix can be obtained by decreasing the content of B and adding Mo of 5~6%. An example of such improved F-3 alloy is shown in Table 3. However, it is supposed that such variation of chemical composition in F-3 may possibly ruin essential characteristics of self-fluxing alloy, good workability thereof, applicability of building-up at a relatively low temperature and the like. Fig. 12 shows a relationship between the content of B in F-3 and a melting point thereof. As is

apparent from Fig. 12, the melting point is substantially constant or kept at a temperature near 1160°C on the solidus line side until the content of B is decreased to about 0.7% and the solidus line starts to raise when the content of B is decreased to 0.5%. On the liquidus line side, the melting point is increased with the decrease in content of B. More particularly, it is about 1250°C and 1320°C when the content of B is 1.5% and 0.7%, respectively.

Under the circumstances, spray welding took place using a single-nozzle spraying torch to carry out a workability test and a sectional examination of a build-up. F-303 which is an improvement of F-3 was used as self-fluxing alloy and a rail steel was used as built-up material. This spray welding test showed that a building-up temperature was somewhat increased due to the increase of the melting point, however, it was found that the alloy still fully possesses satisfactory workability which is an advantage of self-fluxing alloy and the build-up never has any weld flaw caused by self-fluxing alloy itself.

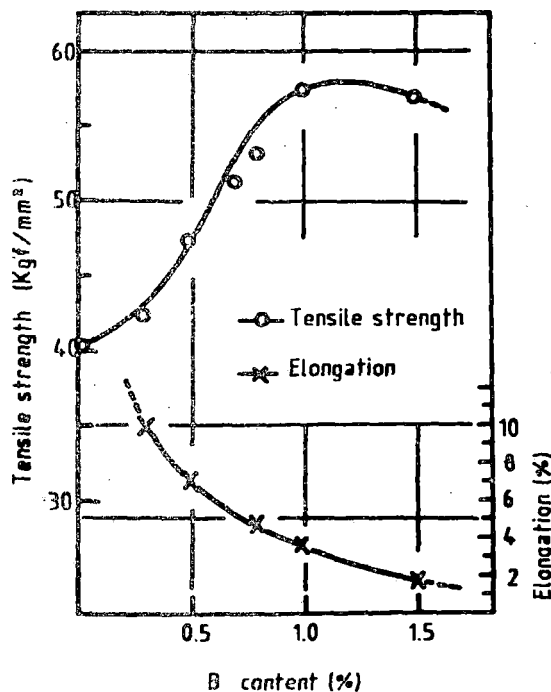


Fig.10 Effect of Boron Content on Mechanical Properties of Ferroalloy

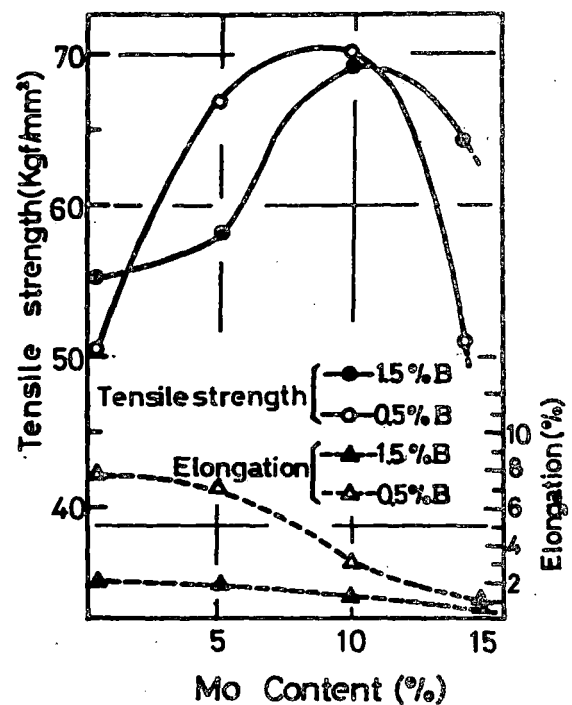


Fig.11 Effect of Molybdenum Content on Mechanical Properties of Ferroalloy

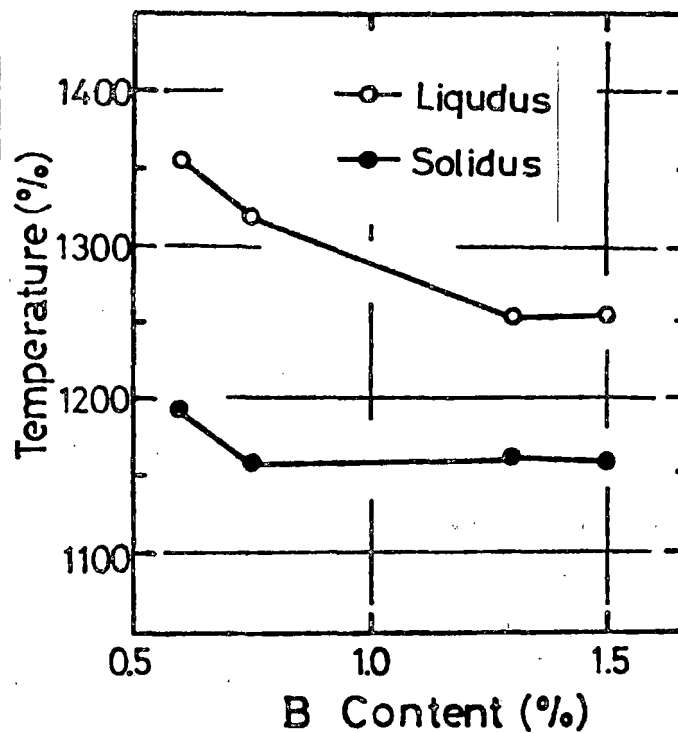


Fig.12 Effect of Boron Content in Self-Fluxing Alloy F-3 on Liquidus and Solidus

Table 3 Chemical Composition and Mechanical Properties of Improved Ferroalloy

| Type  | Chemical composition(%) |      |     |     |     |     | Mechanical properties                   |                |                               |
|-------|-------------------------|------|-----|-----|-----|-----|---|----------------|-------------------------------|
|       | Ni                      | Cr   | B   | Si  | Mo  | Fe  | Tensile strength (Kgf/mm <sup>2</sup> ) | Elongation (%) | Absorbed energy (20°C) (Kg-m) |
| F-303 | 37.0                    | 13.0 | 0.7 | 2.0 | 5.0 | Bal | 60~70                                   | 5~8            | 0.54                          |
| F-307 | 37.0                    | 13.0 | 0.5 | 2.0 | 4.5 | Bal | 55~65                                   | 6~10           | 1.30                          |

### 3.2. Apparatus for Gas-Spray Welding

The most important portion of a gas-spray welding apparatus is a spraying torch. The above-described single-nozzle spraying torch is capable of being used for gas-spray welding of a rail. However, the single-nozzle spraying



torch has a disadvantage that several runs are required to carry out build-up welding over the whole width of tread surface of a rail; because the width of building-up is limited, a build-up is apt to be contaminated by slag at intervals between the runs, and an operating efficiency is significantly decreased. Thus, it is highly desired to develop a multi-nozzle spraying torch which is capable of effectively carrying out building-up over the whole tread surface of a rail at a single run.

### 3.2.1. Multi-Nozzle Spraying Torch

A wide spraying torch including burner nozzles of a basic construction as schematically shown in Fig. 13 was employed through careful consideration on the manner of injecting alloy powder, the manner of supplying alloy powder to a burner, the arrangement of a gas mixing chamber, the arrangement of burner nozzles and the like; and repeated trial manufacture and improvement. The spraying torch is constructed in a manner to arrange gas injection nozzles in two rows in the width direction of a rail, inject alloy powder from a space between the adjacent gas injection nozzles and carry the powder on Ar gas. The forward end of each burner is cooled by water. The width of burners is 80mm. The spraying torch is capable of carrying out building-up of 65mm in width.

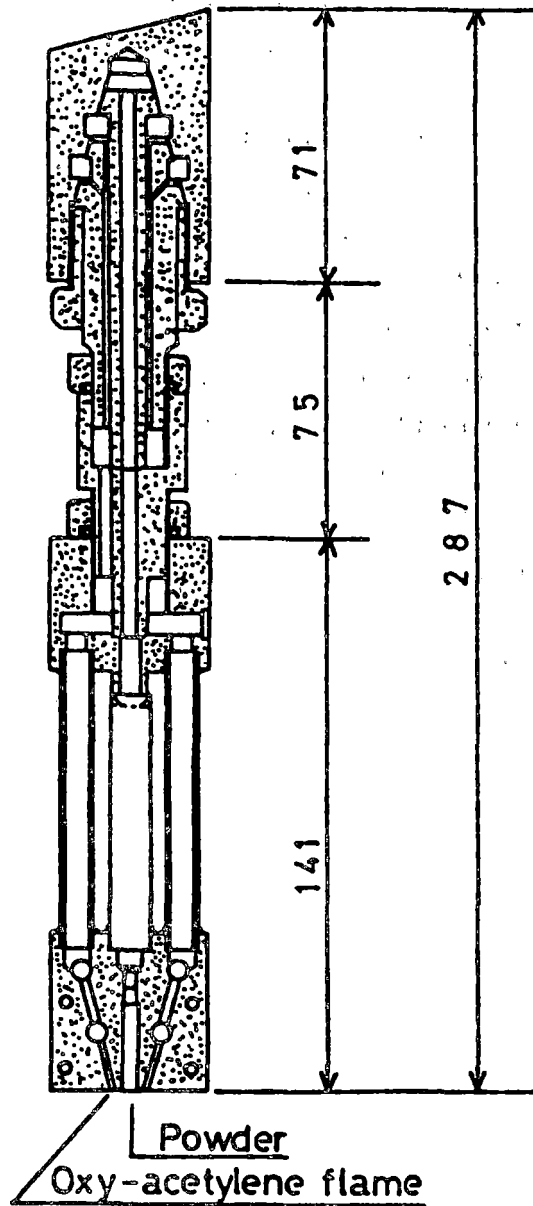


Fig.13 Cross Section of  
Multi-Nozzle  
Spraying Torch

### 3.2.2. Automatic Spray Welding Apparatus

Fig. 14 shows an automatic spray welding apparatus for a rail experimentally manufactured. The apparatus comprises a spray welding section, a control section, a gas flowmeter, a gas bomb, a generator, a cooling water tank, a small truck having these components carried thereon, and the like.

Pre-heating and post-heating (re-melting) burners are disposed on the both sides of a spraying torch which are adapted to be used as desired. However, the apparatus is adapted to allow only the central spraying torch to usually accomplish the entire process of pre-heating, pre-spraying and spray melting (melting treatment carried out concurrent with spraying in order to minimize heat affection on a rail). Also, the apparatus is constructed to carry out the determination of building-up conditions, for example, such as the determination of building-up speed, the determination of travel distance of the spraying torch, the ignition and extinguishing of mixed gas, the supply of alloy powder and the like, by operating buttons of the control section.

Gas-spray welding was carried out on an actual rail using the present spray welding apparatus and the self-fluxing alloy F-303, so that the conditions for build-up welding was carefully considered. The following is an example of the conditions deemed to be proper in view of the appearance of a build-up and internal weld defect observed by an X-ray apparatus:

Pressure and flow rate of gas:

$C_2H_2$  ---  $0.6 \text{ kg/cm}^2$ , 50  $\ell$ /min

$O_2$  ---  $6.0 \text{ kg/cm}^2$ , 48  $\ell$ /min

Supply rate of alloy powder: 15 ~ 20 g/cm

Supply rate of Ar for carrying alloy powder: 20  $\ell$ /min

Spraying distance: 20mm

Spraying speed: 50 mm/min

Pre-spraying speed: 760 mm/min

Building-up procedure:

pre-heating ( $250^\circ\text{C}$ )  $\rightarrow$  pre-spraying  $\rightarrow$  secondary

pre-heating ( $600^\circ\text{C}$ )  $\rightarrow$  spraying (melting)

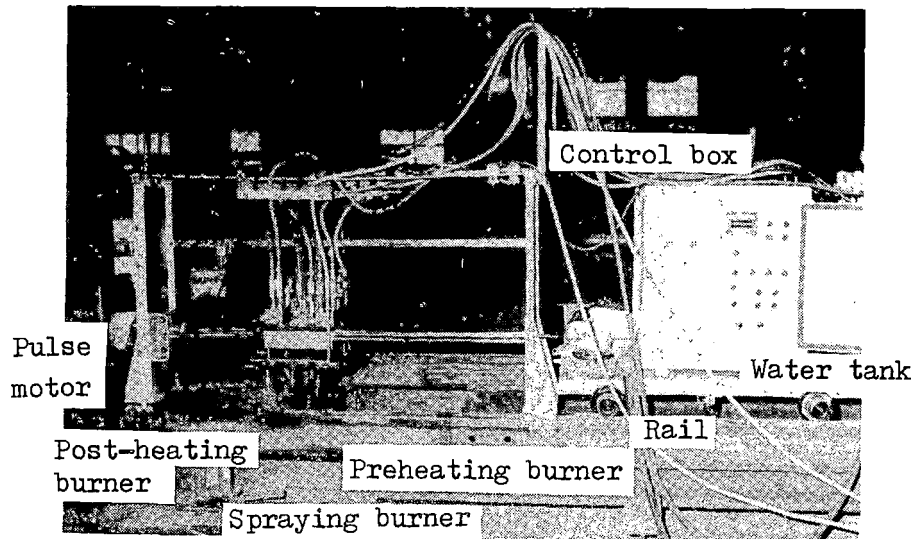


Fig.14 Automatic Apparatus

### 3.2.3. Semi-Automatic Spray Welding Apparatus

In the automatic spray welding apparatus described above, the weight of each part or component is limited to 60kg or less to facilitate the assembling and attaching of the parts. However, in order to further facilitate the operation in the site, it is required to further lighten the parts. In addition, although the automatic spray welding apparatus allows the spraying operation to be readily carried out, there is a fear that it proceeds with the operation while remaining weld flaw in a build-up when the ununiform injection of alloy powder or the turbulence of a heating flame occurs, to thereby hurt reliability. Therefore, it is desired to develop a semi-automatic spray welding apparatus which is constructed to permit an operator to operate it while observing the supply of alloy powder to a zone to be built-up, the movement of a spraying torch, the melting state of a build-up and the like.

Fig. 15 shows a semi-automatic spray welding apparatus experimentally manufactured in view of the above-described two points. The illustrated apparatus comprises a spraying torch, a section for supporting and guiding the torch, a gas

flowmeter and a hand switch section; and the parts or components each are lightened to have a weight of 20kg or less.

The following is standard conditions for build-up welding using the present apparatus:

Distance between spraying torch and tread surface of rail: about 30mm

Pressure and flow rate of gas:

$C_2H_2$  --- 0.6 kgf/mm<sup>2</sup>, 40 ~ 45 l/min

$O_2$  --- 5 kgf/mm<sup>2</sup>, 38 ~ 43 l/min

Flow rate of Ar carrying alloy powder: 5 ~ 10 l/min

Supply of alloy powder: 15 ~ 20 g/cm

Pre-spraying temperature: about 250°C

Pre-spraying speed: 760 mm/min

Spraying speed: 30 ~ 40 mm/min

The semi-automatic spray welding apparatus adopts low flow rate of oxy-acetylene gas, low heating rate and low spraying rate corresponding to the decrease in heating rate, as compared with the above-mentioned automatic one; so that an operator may readily accomplish the control of melting of a build-up.

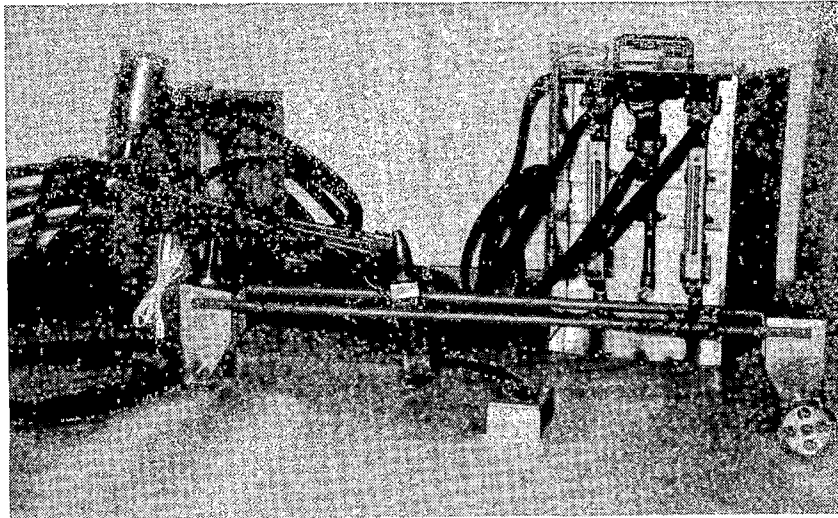


Fig.15 Semi-Automatic Apparatus

#### 4. Properties of Build-Up of Rail by Gas-Spray Welding

##### 4.1. Macro- and Microstructures and Hardness Distribution

Fig. 16 shows one example of appearance of a build-up of a rail, which is of a single layer formed using the self-fluxing alloy powder F-303 and automatic spray welding apparatus. Fig. 17 shows hardness distribution on the tread surface of a build-up formed under the substantially same conditions as in Fig. 16, and Fig. 18 shows microstructure in cross-section of the central portion of the build-up shown in Fig. 17. Also, Fig. 19 shows hardness distribution in the section shown in Fig. 18. As can be seen from Figs. 16 to 19, the occurrence of weld flaw is not observed in appearance of the build-up, and the build-up also does not have any significant problem in the sectional structure and hardness. In addition, it was observed that any remarkable grain growth and any hot crack do not occur in the matrix.

Figs. 20 to 22 show macro- and microstructures, hardness in section, and hardness on the tread surface of a build-up applied to the ground zone of about 5mm in depth using F-307 and the semi-automatic spray welding apparatus. Although several phenomena are observed in these figures such as grain growth of the matrix at the boundary of the build-up, the active dispersion of building-up metal into the matrix and the decrease in hardness of the build-up due to the increase in melting point of alloy powder, the decrease in heating rate and spraying speed, the increase in thickness of the build-up weld and the like; it is concluded that the build-up does not have any significant problem because the occurrence of hot crack is not observed and the decrease in hardness is overcome due to work hardening.

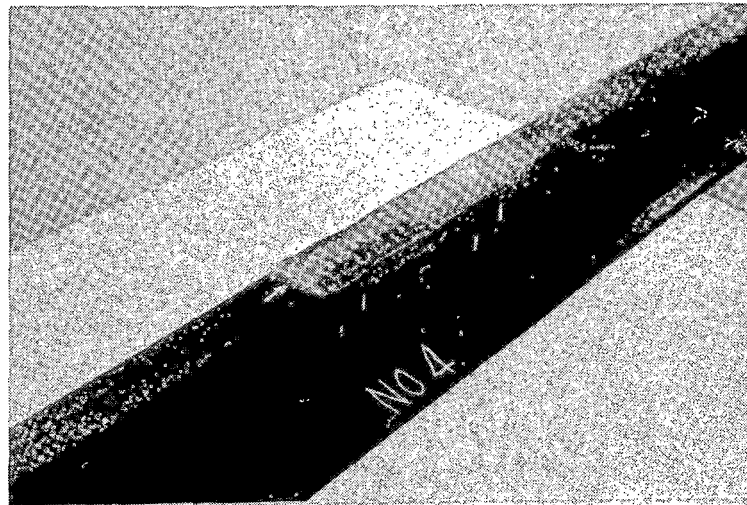


Fig. 16 Appearance of Gas Spray Welded Rail (F-303)

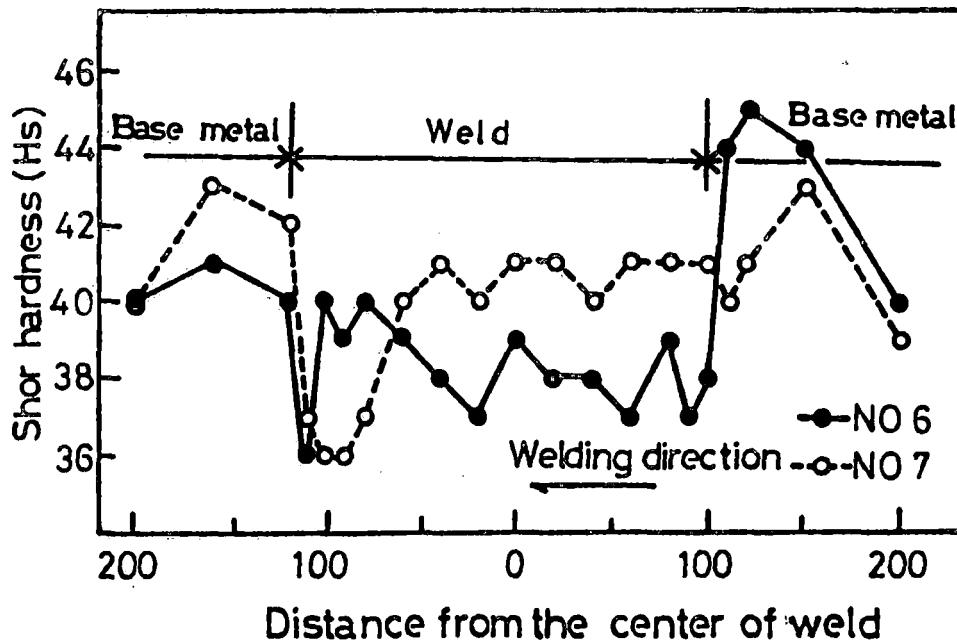
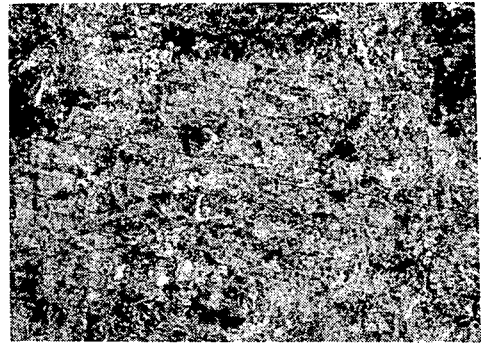


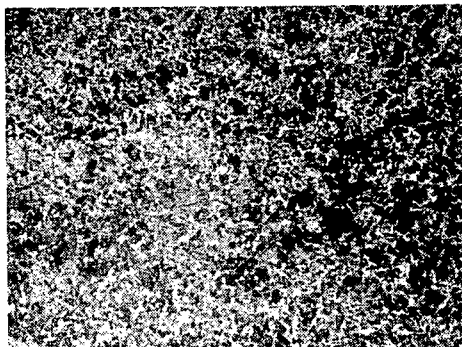
Fig. 17 Hardness Distribution on Tread Surface of Gas Spray Welded Rail (F-303)



NO.1



NO.2



NO.3

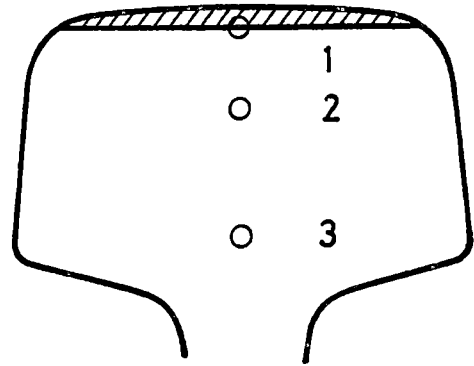


Fig.18 Microstructures in Cross Section of Gas Spray Welded Rail (F-303)



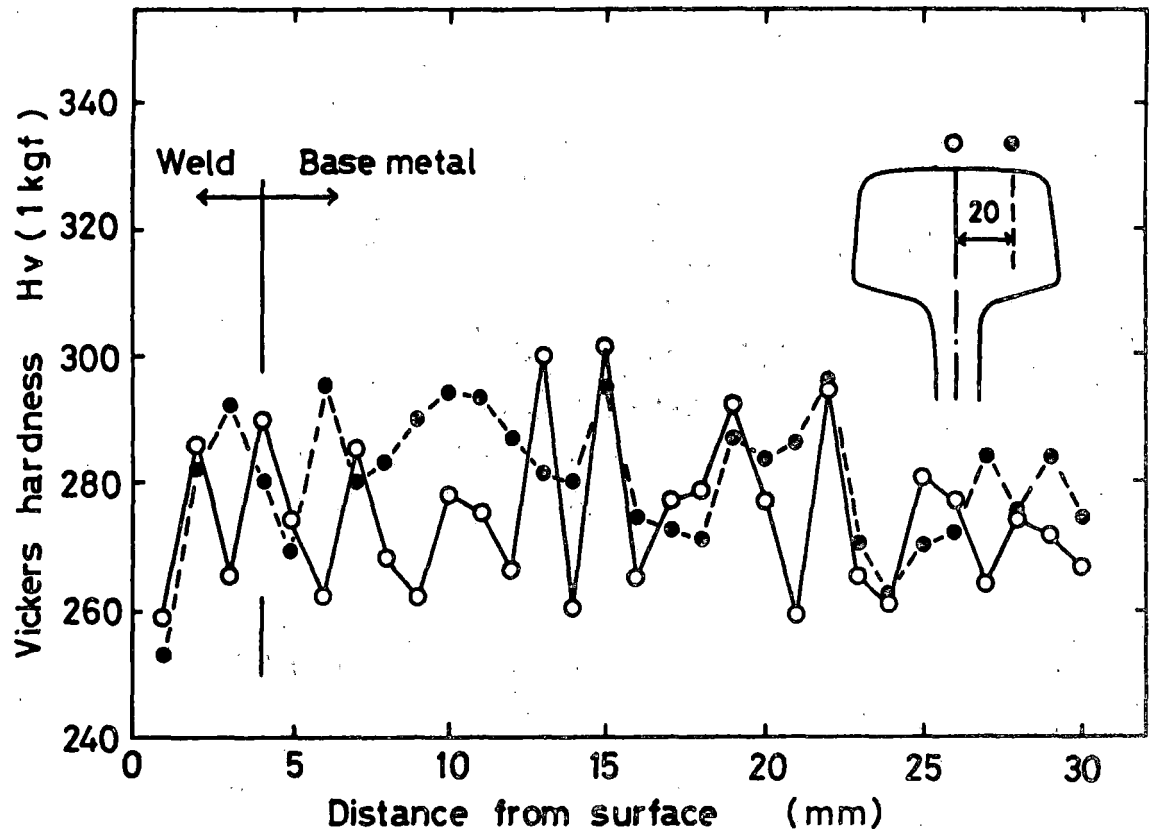
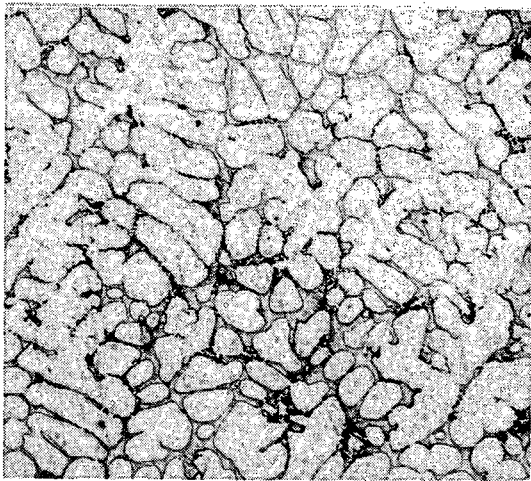
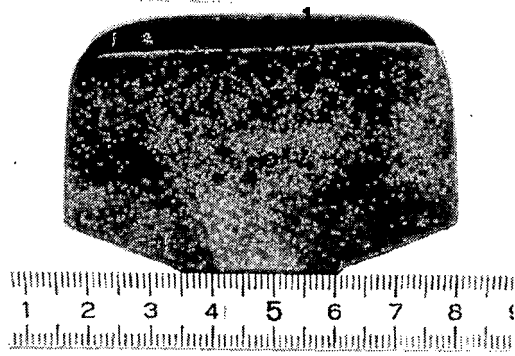
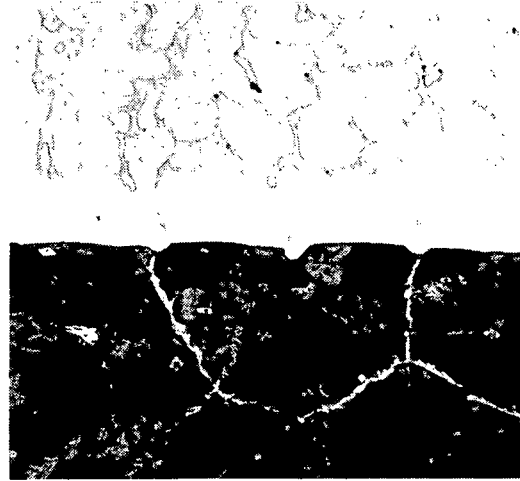


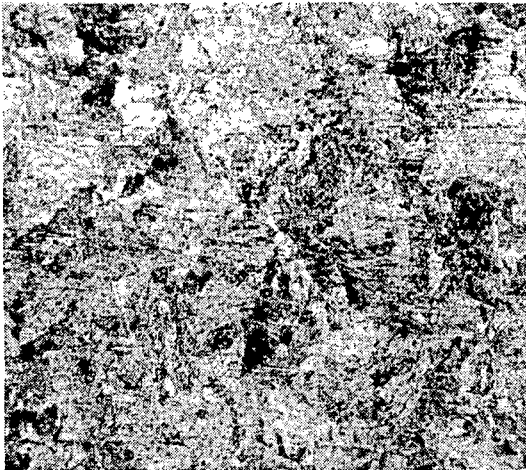
Fig. 19 Hardness Distribution in Cross Section of Gas Spray Welded Rail (F-303)



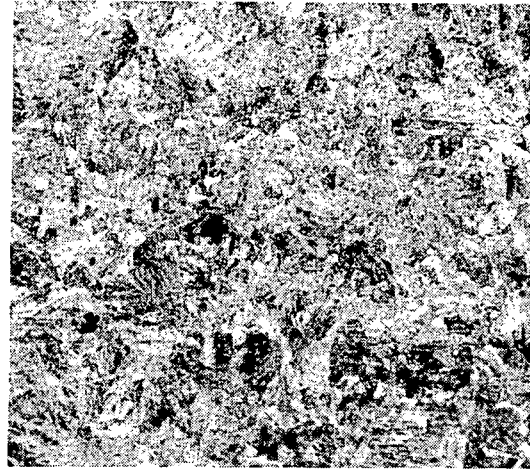
NO.1



NO.2



NO.3



NO.4

Fig.20 Macro and Microstructures in Cross Section of Gas Spray Welded Rail (F-307)

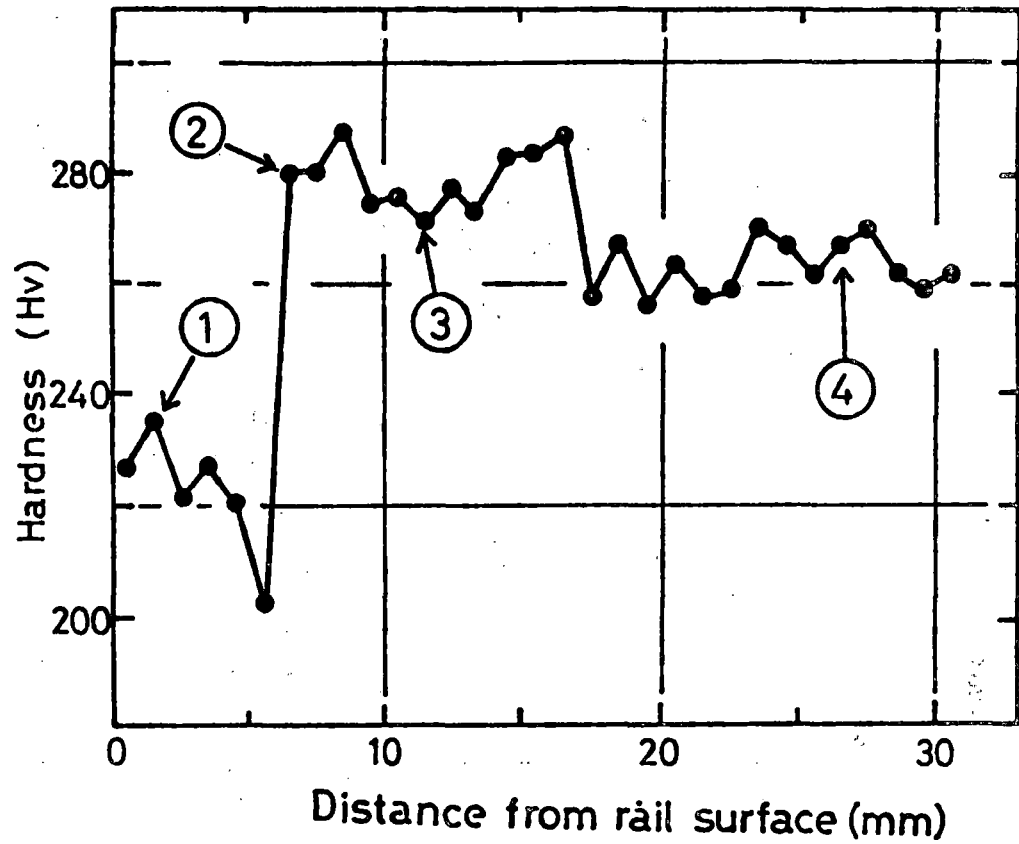


Fig. 21 Hardness Distribution in Cross Section of Gas Spray Welded Rail (F-307)

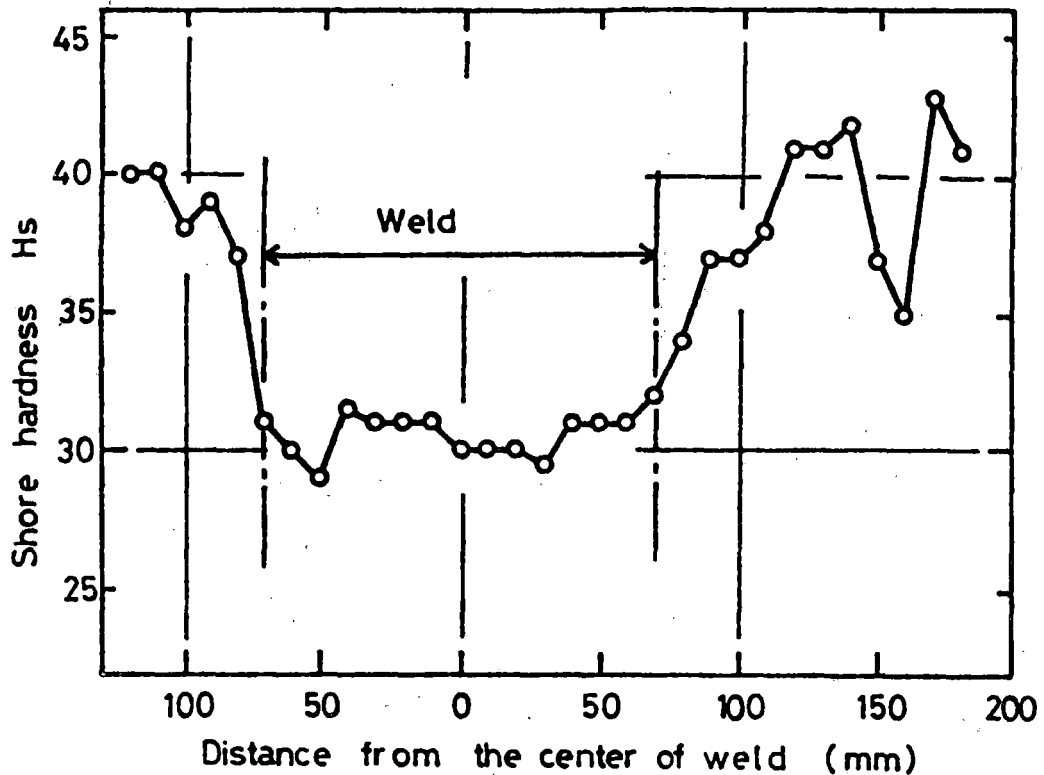


Fig.22 Hardness Distribution on Tread Surface of Gas Spray Welded Rail (F-307)

#### 4.2. Bending Test and Rolling Load Fatigue Test

The evaluation of mechanical properties of an actual rail is generally made using a bending test, a bending fatigue test, a rolling load fatigue test, a drop-weight test and the like. Whereas, a welded rail is typically evaluated particularly by a bending test. The bending test is carried out in a manner to position the weld of a rail at the central portion of span of 1m and concentrate bending load at the central portion of the weld using a pressure element having a tip end of 127mm in radius. In the test, a rail is positioned in the direction of HD wherein a tension is applied to the head of the rail and in the direction of HU wherein a tension is applied to the base thereof. Also, in the bending test, a bending test machine of 250 ton Amsler type for rail's exclusive use is used, and the maximum load and deflection at break are measured. In addition, fracture is observed in detail. The performance of weld of a rail is evaluated synthetically judging the

so-obtained test results.

Table 4 shows results of a bending test carried out on a rail of 50N having a build-up of about 200mm in length formed thereon using F-303 and the automatic spray welding apparatus and arranged in the HD direction. In Table 4, No. 9 designates a one-layer build-up of 2mm in thickness and No. 13 is a two-layer build-up of 3mm in thickness. The build-up of the rail is of fully practical use in view of the fact that any significant defect is not observed at the fracture, and the measured load and deflection at break are satisfactory.

A bending test of the build-up of a rail formed using F-307 and the semi-automatic spray welding apparatus was repeated many times (about 100 times). Specimens used each had a three-layer build-up of about 200mm in length and 5~6mm in thickness applied thereto. Most of built-up rails are a rail of 50N removed from a track. The results were that load at break ( $W$ ) is 80 to 107 tons and deflection ( $\delta$ ) is 12 to 30mm, and the averages of  $W$  and  $\delta$  are respectively 85~87 tons and 16~17mm. The results are somewhat inferior to those of Table 4, however, this will not substantially affect the practical use.

A rolling load fatigue test was carried out using a test machine schematically shown in Fig. 23 and under the conditions that load, rolling velocity and rolling width are respectively set at 20 tons, 80 CPM and 260mm. The test was also carried out in a manner that all build-up, the periphery of build-up, the heat affected zone of matrix and the unaffected zone of matrix are in the range of rolling. The build-up was formed using F-303 and the automatic spray welding apparatus. In the test, any defect did not occur even at  $10^6$  in the number of rollings, and the rolling surface of both build-up and matrix was uniformly worn as shown in Fig. 24 and did not have any problem.

Table 4 Result of Bending Test of Gas  
Spray Welded Rail(Head Tension-F-307)

| Test piece | Failure lod(ton) | Deflection (mm) |
|------------|------------------|-----------------|
| NO 9       | 110              | 30              |
| NO 13      | 107              | 27              |

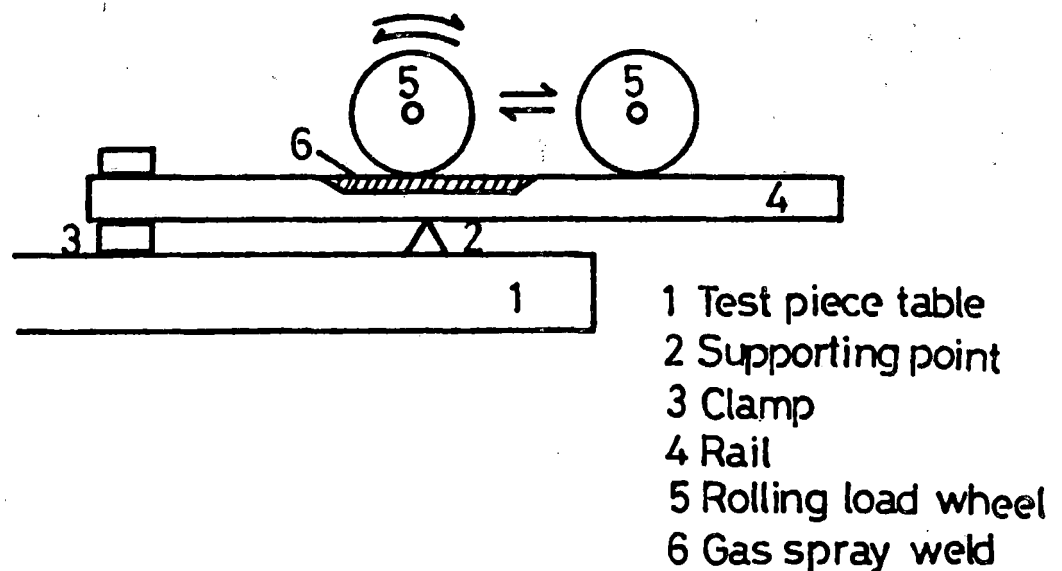


Fig. 23 Schematic Diagram of Rolling Load  
Fatigue Machine

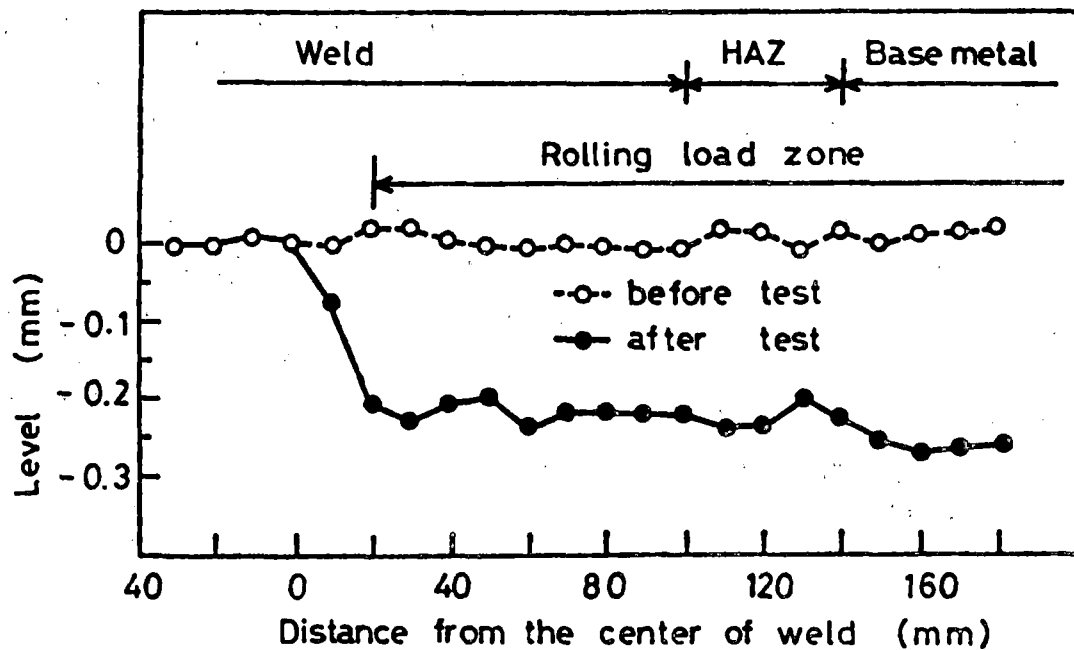


Fig.24 Difference of Longitudinal Level between Ante Rolling Load Fatigue Test and Post Rolling Load Fatigue Test

#### 4.3 Spray Welding Test on Rail Laid

A spray welding was experimentally carried out with respect to four engine burns on a rail of the Chikuho line (Kyushu) in March, 1977 to study an effect of spray welding on a rail which is actually laid. This is a rail of 50kg having the head subjected to heat treatment, of which passing tonnage was 1,700,000 tons and the curvature radius (R) was 400m. F-303 and the automatic spray welding apparatus were used in the test.

Fig. 25 shows variation in hardness distribution and smoothness of the tread surface of the built-up rail with time. As shown in Fig. 25, the hardness is increased at passing tonnage 180,000 after spraying and not changed thereafter. In connection with the smoothness, local wear occurs in the softening zone of the matrix on one side of the tread surface. However, any peeling and cracking is not observed, thus, it is concluded that the present spray welding method can be fully put into practical use.

Also, spray welding utilizing F-307 and the semi-automatic spray welding apparatus was also experimentally accomplished on a rail of a line of which passage tonnage is relatively much. The build-up was increased in hardness in a short period of time after spraying. Local wear was somewhat observed in the softening zone of matrix of the rail, however, this was not significantly much in amount.

Based on the test results described above, JNR (Japanese National Railways) has put the present spraying welding method into practical use for repairing engine burns of a rail.

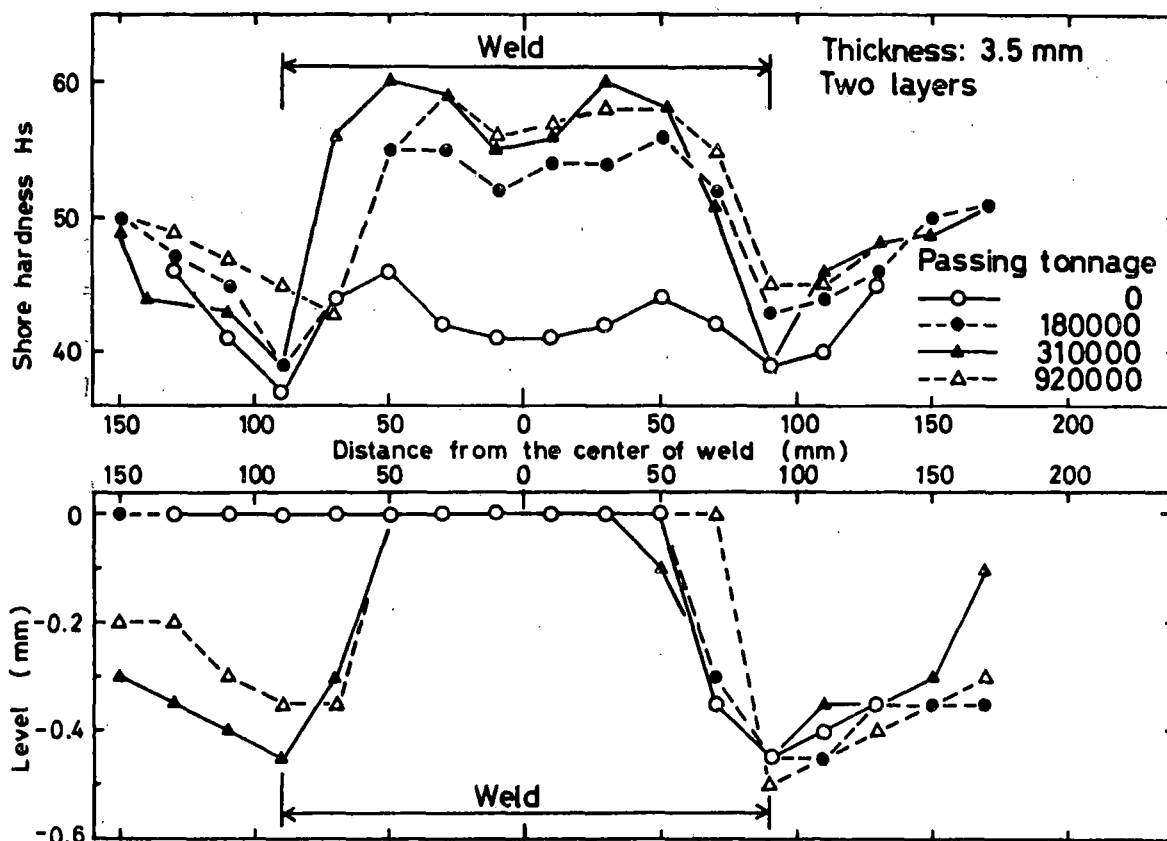


Fig. 25 Variations in Hardness Distribution and Longitudinal Level on Tread Surface of Gas Spray Welded Rail



## 5. Welding Procedures and Example of Application of Gas-Spray Welding

The number of engine burns repaired according to the present gas-spray welding method has reached about two hundred (200). This resulted in a satisfactory result being obtained.

The build-up welding operation of a rail using the present gas-spray welding method is carried out according to the following procedure.

(1) First, fastenings in proximity to engine burn are removed and then a rail is provided with a suitable amount of prestrain by means of a jack depending upon the dimensions of the rail portion to be built-up. Then, the engine burn is removed by grinding and it is inspected whether or not any harmful flaw or defect such as crack or the like appears on the ground surface. When any flaw is observed, the ground surface is further subjected to a grinding treatment (Fig. 26).



Fig.26 Grinding of Engine Burn

(2) A spraying torch and a member for supporting the torch are arranged above the rails (Fig. 27). The supporting member has two rollers mounted on the lower end, so that the spraying torch may be moved on the rails. Then,

self-fluxing alloy powder is charged in a hopper disposed above the spraying torch, and the pressure and flow rate of each of oxygen, acetylene and argon are adjusted.

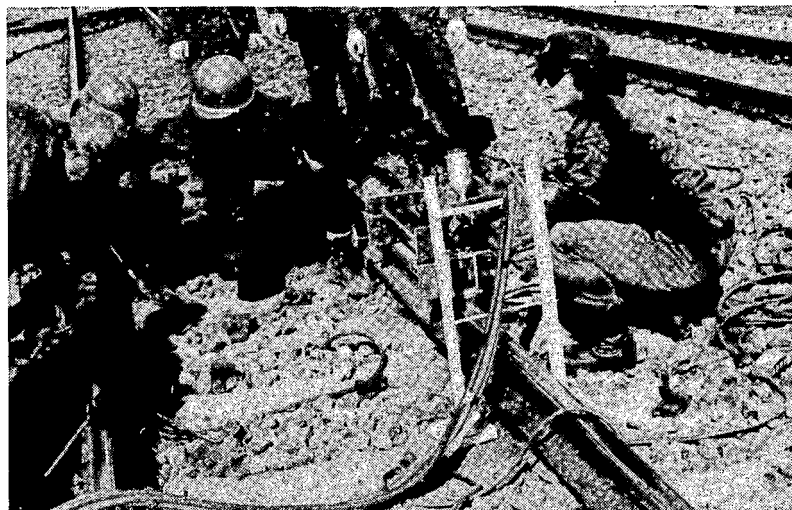


Fig. 27 Installation and Adjustment of Apparatus

(3) The spraying torch is ignited and swingably moved to heat the whole ground tread surface of the rail to about 250°C. When the temperature of the ground tread surface reaches a predetermined level, a button of a hand switch is pushed to flow argon gas, to thereby initiate spraying of alloy powder. At this time, the swinging of the spraying torch is increased in velocity to allow a very thin layer of spraying metal to be formed in a short period of time. (This step is referred to as "pre-spraying".) (Fig. 28).

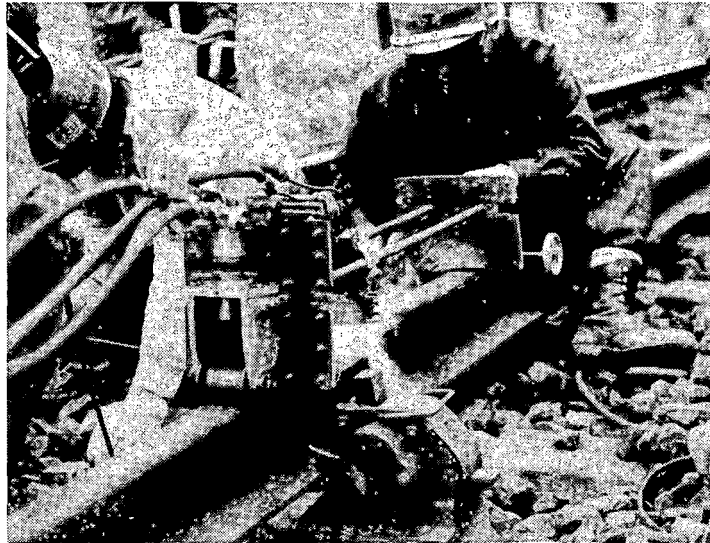


Fig.28 Pre-Spraying

(4) After completion of the pre-spraying, the supply of alloy powder is stopped and the whole pre-sprayed zone is pre-heated to about  $600^{\circ}\text{C}$ . Then, the spraying torch is fixedly positioned near the end of the zone to be built-up to initiate spraying and melting. When the melting of alloy powder is confirmed, the spraying torch is moved a small distance to start spraying and melting again. The spray welding is successively carried out in such manner (Fig. 29). In this connection, attention should be paid not to cause the molten metal to hang down from the tread surface of the rail during the operation.

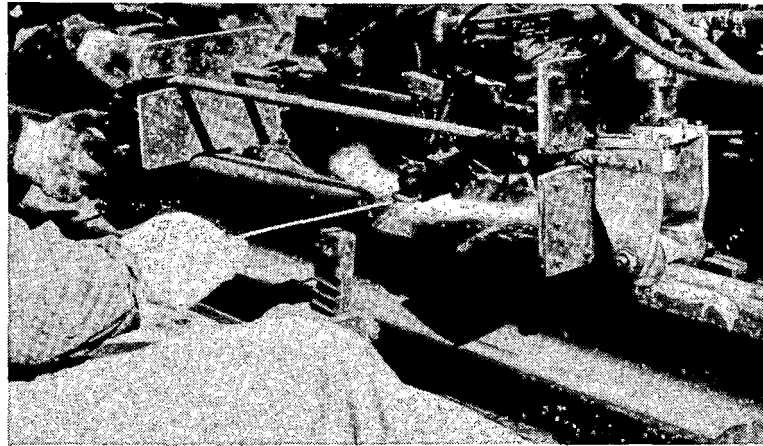


Fig.29 Gas Spray Welding

(5) After completion of the spray welding, hand switches are operated to stop the supply of alloy powder, extinguish gas flame and remove the spraying torch (Fig. 30).

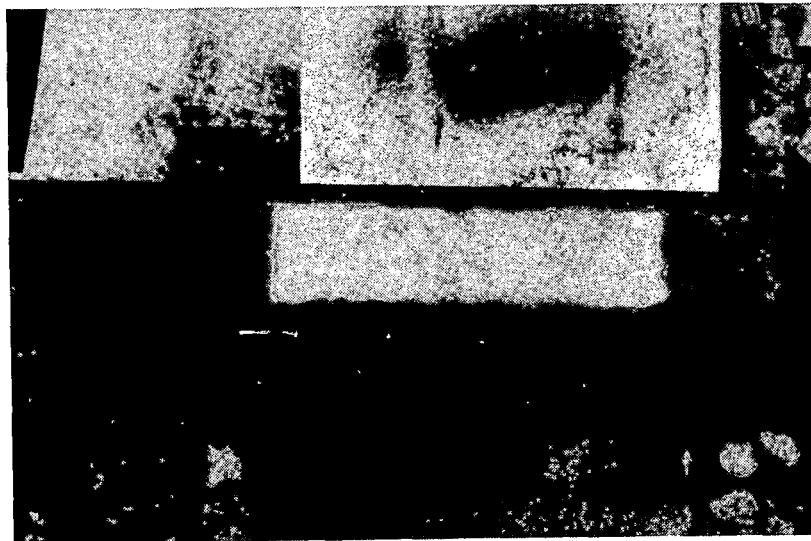


Fig. 30 Appearance immediately  
after Gas Spray Welding

(6) The removed fastenings are mounted on the rail and ground finish is carried out by grinding excess metal of the build-up and aligning line and level (Fig. 31). Finally,

a test such as Dye Penetrant Test or the like is carried out, so that all the steps of the operation are completed.



Fig.31 Final Grinding for Meeting Track Geometry Standard

The time required to carry out the operation is varied depending upon the dimensions and degree of engine burn. The following is an example of the time required to repair engine burn of 200mm in length and 6mm in depth generated in a continuous welded rail by building-up of two layers.

- (1) Grinding (including operating time required for the removing of fastenings and the like): 15 minutes
- (2) Pre-heating and pre-spraying: 5 minutes
- (3) Pre-heating and spray welding: 10 minutes
- (4) Finishing and fastening: 20 minutes
- (5) Visual inspection and Dye Penetrant Test; putting in order: 10 minutes

The above-described spray welding operation experimentally carried out required 60 minutes in all. However, it is a matter of course that the time required will be considerably varied depending upon the operational skill of an operator.

Fig. 32 shows an example that the present gas-spray welding was applied to battering and peeling generated at the end of a rail, and Fig. 33 shows an example that it was carried out on the nose rail of welded crossing. As shown in these figures, the welding was carried out with a single-nozzle spraying torch. The single-nozzle spraying torch is often used for the repairing of minor engine burn.

The spray welding applied to the end and crossing nose now is subjected to a follow-up. Any defect is not observed at the present.

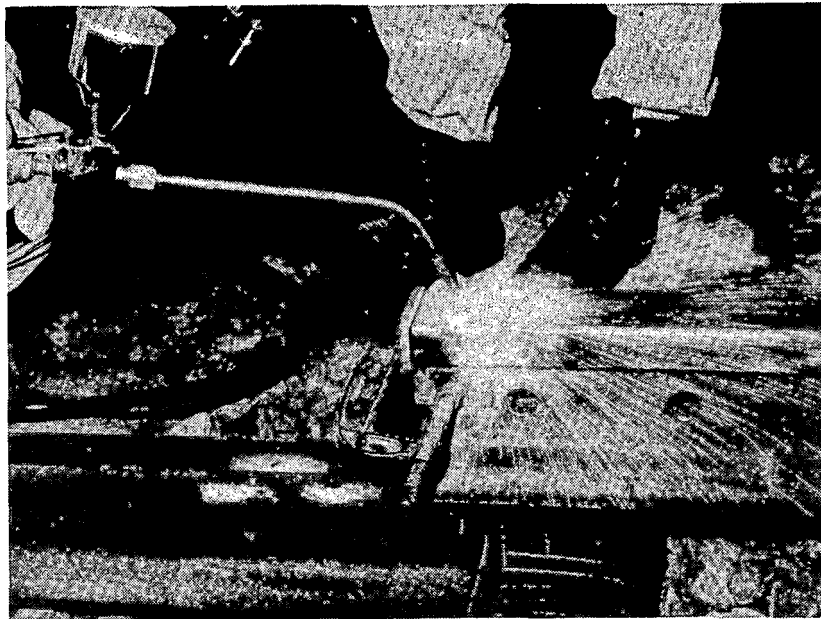


Fig.32 Gas Spray Welding for Rail  
End Batter



Fig.33 Gas Spray Welding  
for Nose Rail of  
Welded Crossing

#### 6. Concluding Remarks

It is supposed that the reasons why the build-up welding of a rail which is widely put into practical use in foreign countries is not substantially utilized are based on not only the difference in material of a rail but the difference in understanding with respect to the performance and reliability of weld of a rail. Whereas, it is true that the development of a method for repairing damage on the tread surface of a rail in the site is of urgent necessary. In order to meet such requirement, the authors developed gas-spray welding utilizing the Ni-Cr-Fe base self-fluxing alloy powder and proved that the gas-spray welding can be

effectively applied to repair engine burn of a rail. Only one year and a half have passed after the gas-spray welding was substantially put into practical use, however, good results are obtained at the present.

A study will be made on a method of narrowing the softening zone of a rail to minimize the above-described local wear at the heat affected zone of the matrix and also on extensive application of the present spray welding to the local wear at the end and crossing nose in future.

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- (1) M. Otani, "A Study of Filler Rod for Building Up Rail" Journal of The Japan Welding Society (in Japanese), Vol. 16 (1947), No. 3, 195-200
- (2) "An Investigation of Various Welding Techniques for Building Up Battered Rail End" A.A.R. Research Department Report No. ER-32 (1963) March
- (3) H. Euken, "Geräte für die Lichtbogenauftragsschweißung im Betriebsgleis der Deutschen Reichsbahn", Signal und Schiene, 18 (1974), 5 155-159
- (4) P. Gence, L. HanHebique, "La réparation des rails en voie par soudage automatique" Revue Générale des Chemins de Fer, FEVRIER, 1973-92<sup>e</sup>, ANNEÉ, 114-119
- (5) "Speed Rail-end by Welding" Railway Track and Structures, Vol. 58 (1962) No. 9, 35-37
- (6) "ICG favors cored-wire electrode for rail and frog maintenance" Railway Track and Structures, Vol. 71 1975, July, 18-19
- (7) "Santa Fe adopts flux-cored wire for rail-end build-up" Railway Track and Structures, Vol. 73, 1977, July, 22-23
- (8) L. Nekand-Trepka, J. Kaczor, "Auftragssweißen von Schieuestahl mit Molybdän-Mangan-Zusatzwerkstoff", Schweisstechnik, 28, (1978), 3, 117-119
- (9) C. Cookson, Fleetwood Shave "Reclamation of Rails by Powder Welding", Railway Gazette, Vol. 126 (1970), No. 9, 350-351
- (10) K. Hiratsuka, C. Ito, "Spot Welding of Anti-Corrosive Steel Sheets" Railway Technical Research Report (in Japanese), No. 461 (1965) Apr.



APPENDIX B

LABORATORY REPORT  
ON JNR GAS-SPRAY WELD BUILD-UP EXPERIMENT

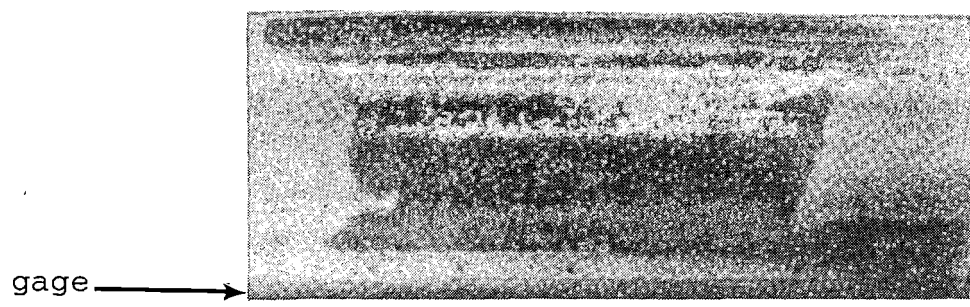
## 1.0 EXPERIMENTAL PROCEDURE

Both welds were visually examined for the presence of cracks, spalling, flaking, bond separation, or any other features that would help in determining material wear and performance as well as metal flow and battering. Both JNR and TTC welds removed from Section 14 of FAST can be viewed in Figure B-1. All the unusual features were photographed. Rockwell-C hardness measurements were taken longitudinally on the running surface of each individual weld, beginning at the center and traversing outward at one-quarter inch intervals. (Refer to Figure B-3.)

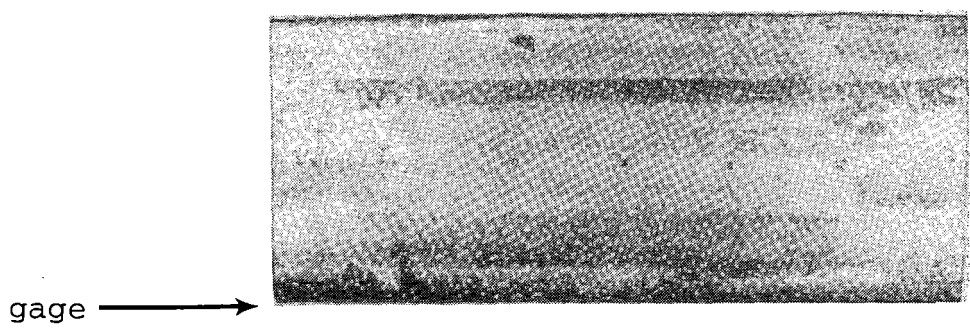
The welded sections were then cut to provide the pieces for metallography, electron microscopy, macroetching, and hardness testing. The sectioning was done in three steps. In the first step, the head was cut from the rail. The second step involved cutting three samples from the center portion of the weld build-up deposit, as shown in Figure B-2. The slices produced from these cuts were marked No. 1 through No. 3 and were used for scanning electron microscopy (SEM), microstructure evaluation, microhardness mapping, and macroetching.

After first-step sectioning, slice No. 3 from both samples were deep-etched in a solution of 4-percent nital for 30 seconds at room temperature. The purpose for this etching is to reveal the boundaries of the heat-affected zone (HAZ) and to detect any inclusions, cracks, and voids in the weld deposition.

Microstructure and microhardness tests were conducted on the No. 2 slice of each sample. (See illustration in Figure B-4.) A comparison of running surface morphology on the No. 1 weld sample for each weld was done using scanning electron microscopy.



JNR



TTC

FIGURE B-1. OVERALL VIEW OF BOTH WELD SAMPLES  
REMOVED FROM SECTION 14 OF FAST

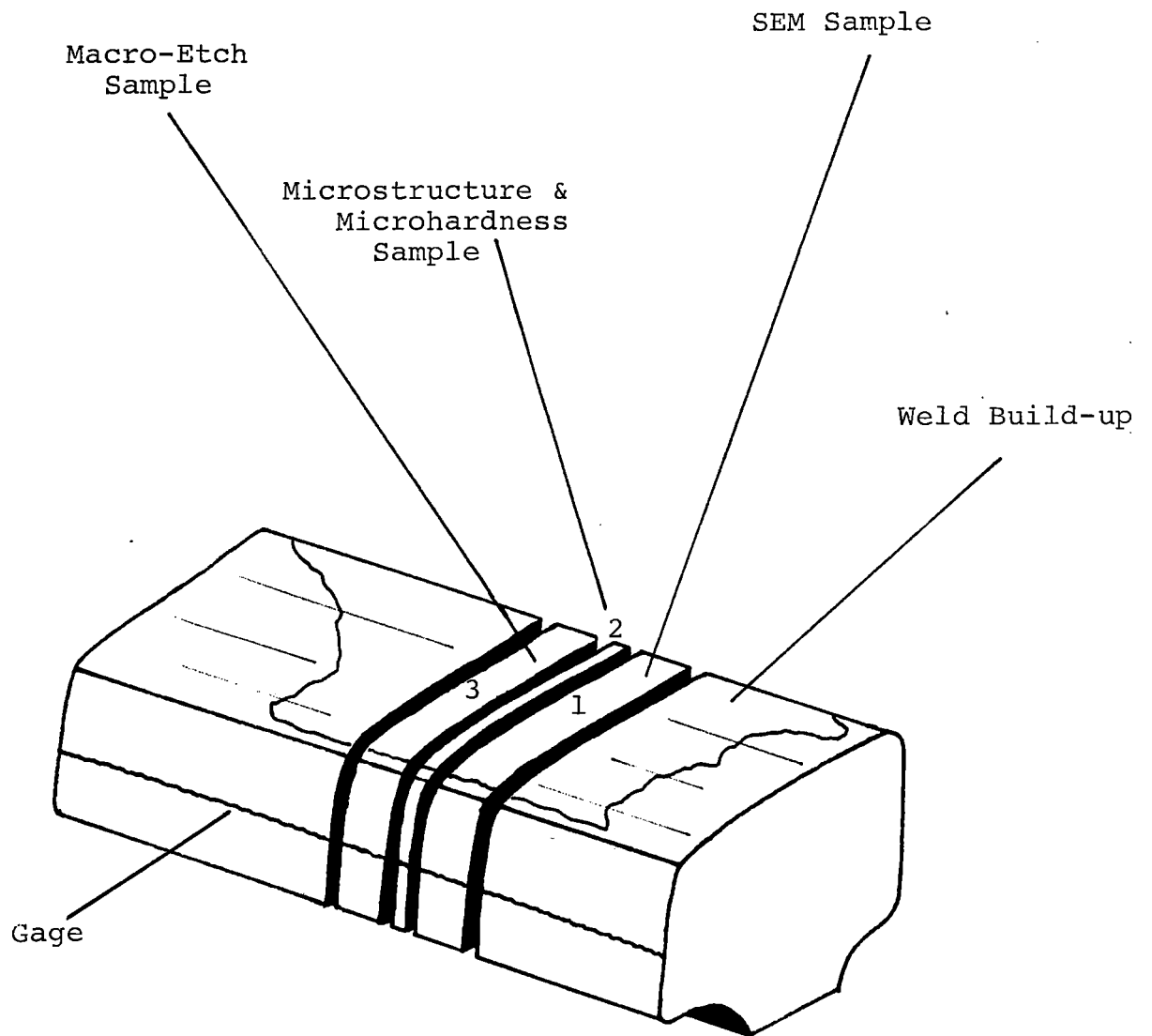
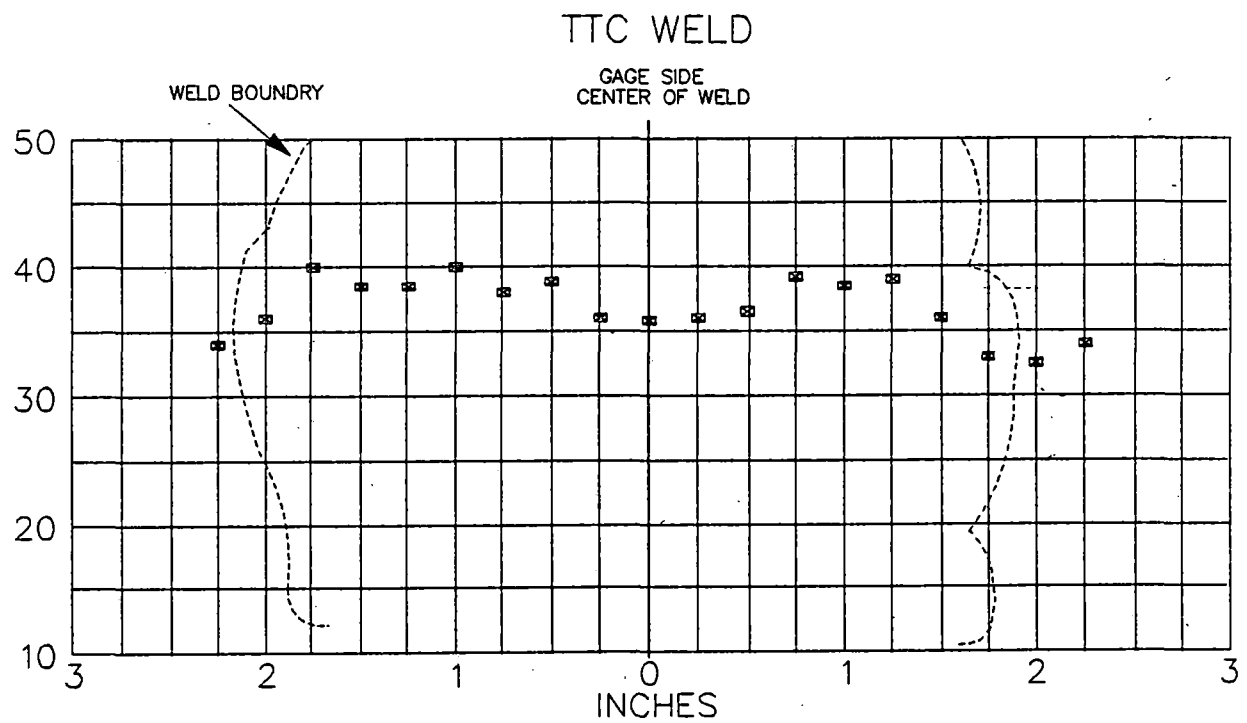
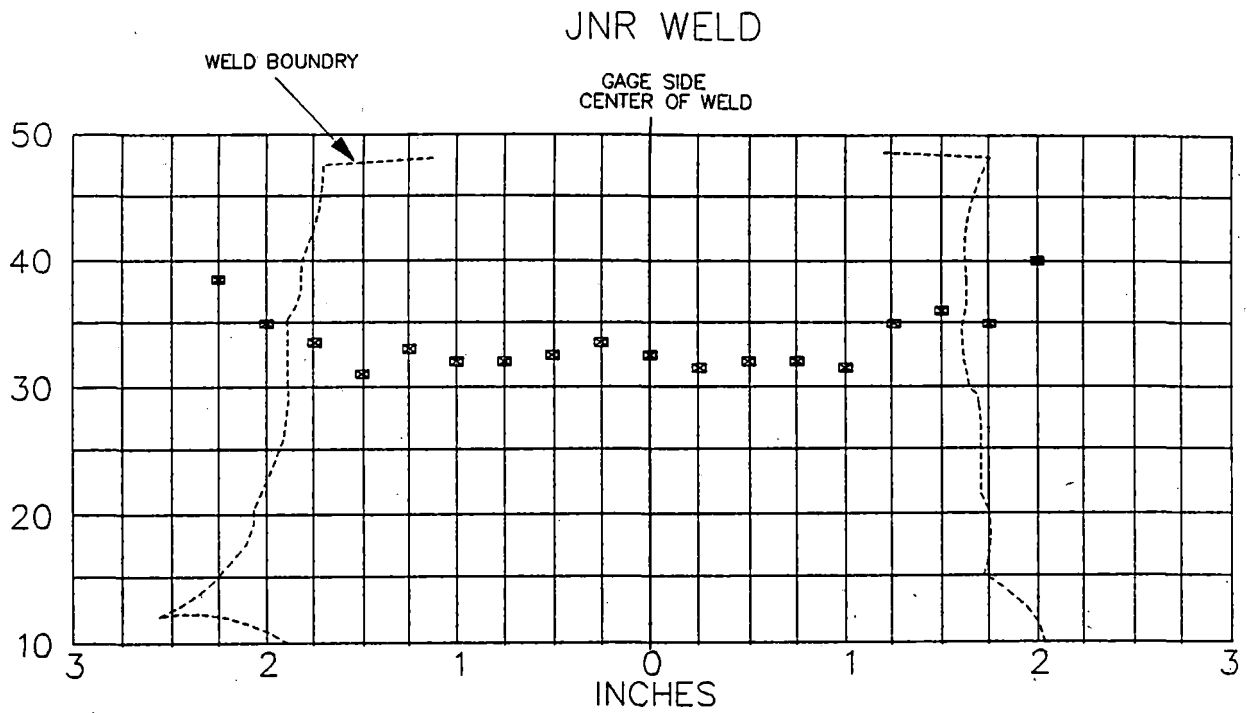


FIGURE B-2. SECTIONING DIAGRAM FOR JNR AND TTC BUILD-UP WELD



**FIGURE B-3. ROCKWELL-C HARDNESS TRAVERSE ON RUNNING SURFACE OF JNR AND TTC WELDS**

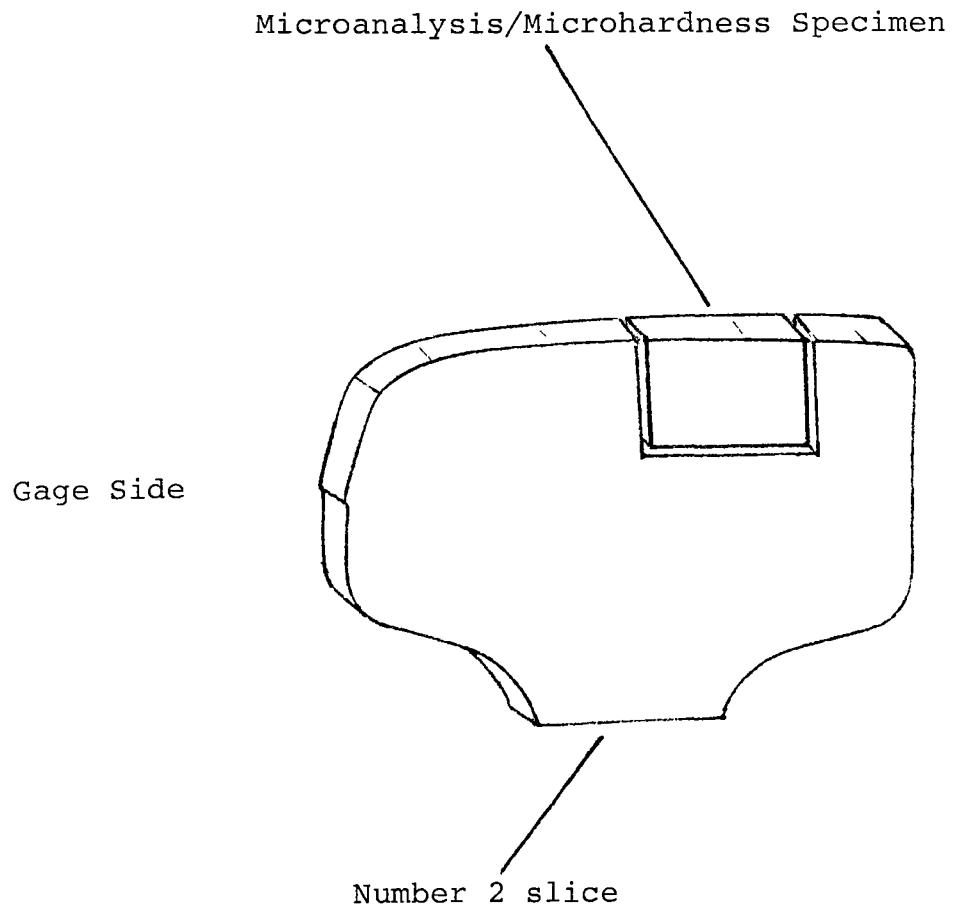


FIGURE B-4. LOCATION OF SPECIMEN USED FOR MICROANALYSIS AND MICROHARDNESS TESTS FOR BOTH JNR AND TTC WELDS

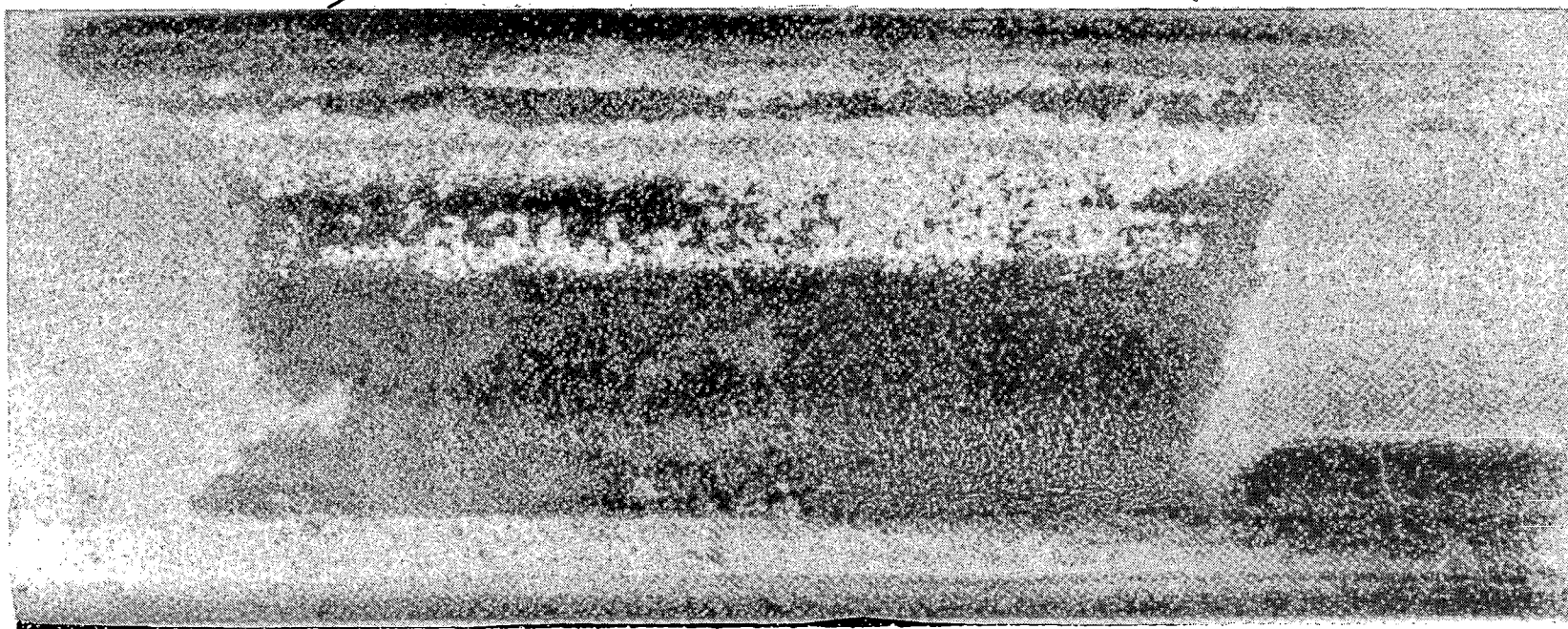
## 2.0 RESULTS AND DISCUSSION

When observed, the running surface of the JNR weld appeared to be rough and dark in color, whereas the TTC weld was smooth and shiny, closely resembling that of the parent metal. Figures B-5 and B-6 show these features. No apparent cracks or spalling could be found in either of the weld repairs. A small chip (4 mm) fell out near the field corner of the TTC repair at about 40 MGT, but no significant changes on the running surface occurred as a result of it. This chip was probably caused by a slag inclusion. Both welds experienced some metal flow, although it was more evident in the JNR weld. Much of the metal flow in the JNR weld was in the longitudinal direction along the field side of the rail. Metal flow in the TTC weld flowed only to the field side of the rail. No longitudinal metal flow was observed in the TTC weld.

Secondary batter occurred 3 inches on each side of the JNR weld. The extent of batter for both welds can be seen in the longitudinal rail profiles given in Figure B-7. When a stereo microscope was used to examine surface details of both weld samples, it was found that the surface matrix of the JNR weld was comprised of flakes on the entire surface. The dark appearance of the JNR weld may have been caused by track lubrication entrapped within the coarse surface texture formed by the flakes. The TTC weld appeared smooth and displayed a few minor pits. No weld bond separation at the edges of the weld boundaries was seen in either the JNR or TTC weld.

Longitudinal Metal Flow

Field Side



B-7

FIGURE B-5. CONDITION OF JNR AFTER REMOVING FROM SECTION 14 OF FAST



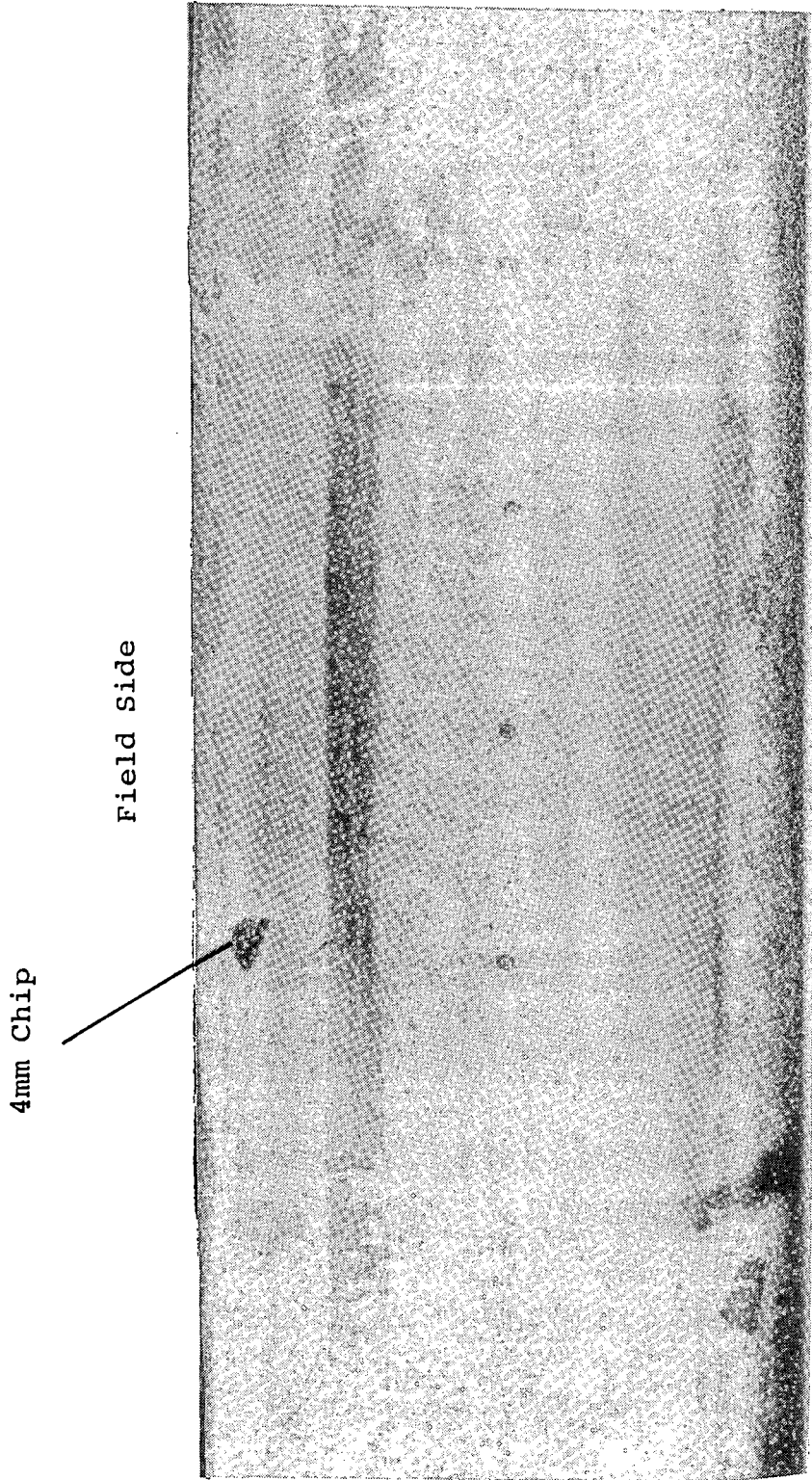
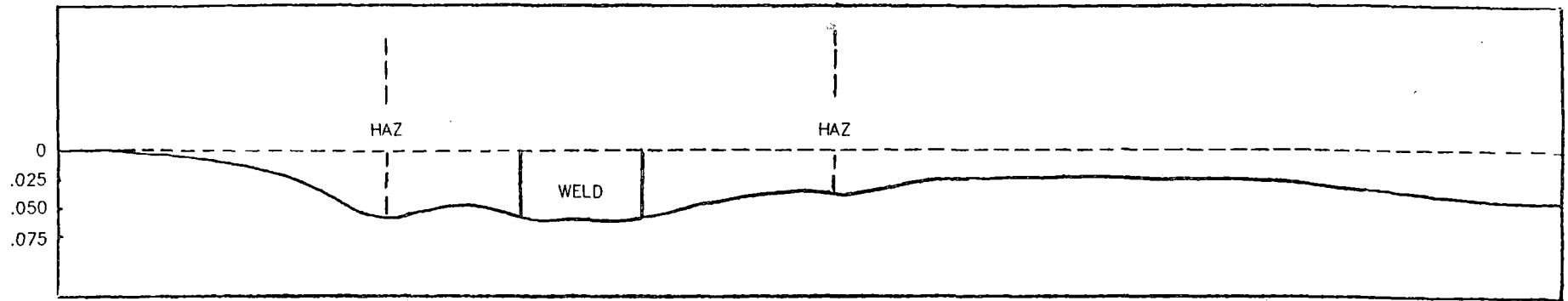
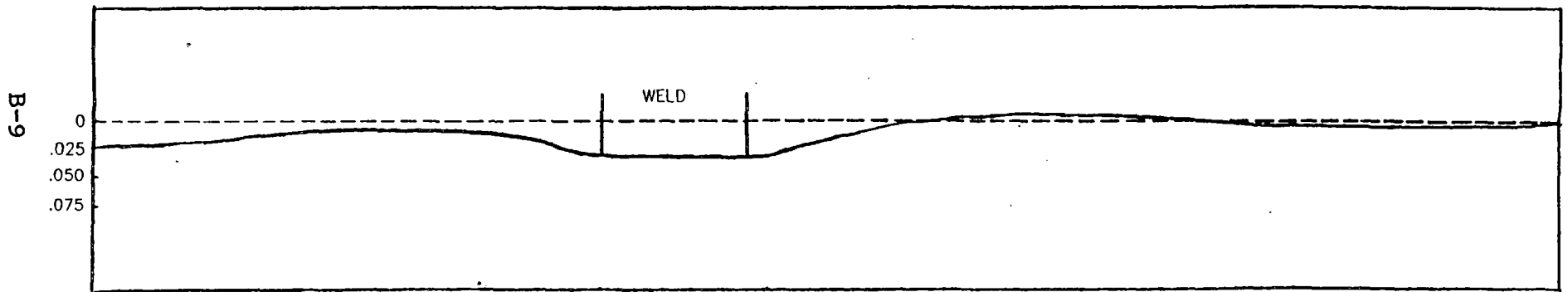


FIGURE B-6. RUNNING SURFACE OF TTC WELD AFTER 60 MGT OF SERVICE



JNR GAS-SPRAY WELD, SECTION 14, TIE 337 ISR



TTC ELECTRIC ARC WELD, SECTION 14, TIE 333 ISR

FIGURE B-7. LONGITUDINAL RAIL PROFILES OF JNR AND TTC WELDS AFTER 60 MGT

Macroetching of the JNR and TTC laboratory weld samples revealed interesting findings pertinent to the size and position of HAZ's. Longitudinal sections were removed from the center of each weld (Figure B-8) and etched in a boiling aqueous solution of 50 percent HCl and 50 percent H<sub>2</sub>O. Photographs in Figures B-9 and B-10 show the results of this test. The JNR weld exhibited only one HAZ, but it was extremely wide; approximately 12 inches. The alloy austenitic deposit metal exhibited no chemical affinity for the etching solution and appears white in Figure B-9. The TTC weld revealed several HAZ's, but were narrow in width and were confined to underneath the deposit metal. Because the soft HAZ's are located under the weld deposit and not exposed to the running surface, less batter is likely to occur in rails with this type of HAZ configuration.

No cracks, porosity, or inclusions were found in either sample. A cross-section of the No. 3 slice from each weld sample removed from track was etched in a 4 percent nital solution to study features on the transverse vertical plane of the head. As can be seen in Figure B-11, very little original deposit metal remained on the running surface (approximately .5 mm at the center of the head) of the JNR weld. However, the TTC weld displayed 1.25 mm of weld metal remaining near the center of the head; 1 mm still remained on the upper gage corner. Because of the absence of deposit metal remaining on the running surface of the JNR sample, microhardness and microstructure studies were conducted near the field side of both samples.

Specimens were cut from the field side of each sample's No. 2 slice for microhardness and microstructure analysis (Figure B-4). The resistance of the gas-spray's high-grade austenitic weld deposit to etch, special optical effects were used to enhance the microstructure. Nomarsky prism was used to enhance the austenite weld structure for microanalysis (Figure B-12). The first deposited layer at the weld/parent metal interface showed a solid bond free of voids and inclusions, with no signs of brittle martensite in the adjacent base metal. As it nears the surface,

the dendritic build-up metal arches in the direction of the metal flow. The high-grade austenitic JNR weld showed signs of delamination and metal flow on the running surface. (See Figure B-12.)

A two percent nital etch was used to bring out the columnar grain structure of the TTC electric-arc weld deposit (Figure B-13). The M-932 build-up electrode rod produces a low-carbon, low-chromium tempered martensitic structure. After 60 MGT of loading, the build-up material displayed high wear resistance to 33-ton axle loads.

Surface studies using scanning electron microscopy (SEM) was conducted on the field side of the No. 1 slice of each sample (Figure B-14). Each sample was cleaned ultrasonically in a solution of methanol to remove any debris left over from the cutting operation. Extreme flaking and metal flow was evident in the JNR sample (Figure B-15). The flaking was mainly oriented in the longitudinal direction to the rail axis. SEM micrographs of the TTC weld in Figure B-16 display a surface free of heavy wear and flow.

Microhardness tests of both samples indicate the TTC weld to be on an average of 35 knoop hardness number (KHN) points higher in hardness than the JNR weld. Figure B-17 shows hardness maps of each sample.

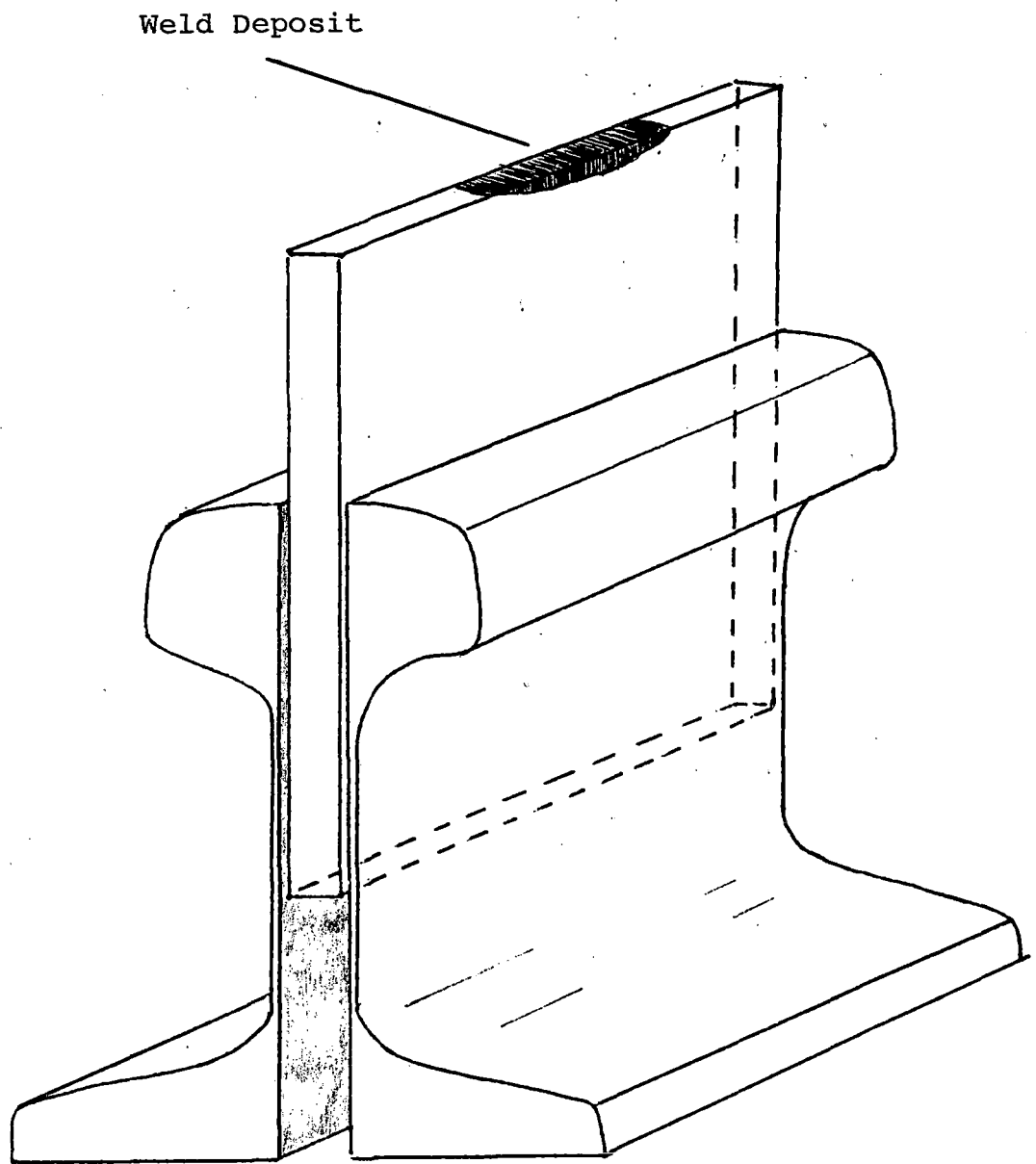


FIGURE B-8. SAMPLE USED FOR MACROETCHING JNR AND TTC WELDS

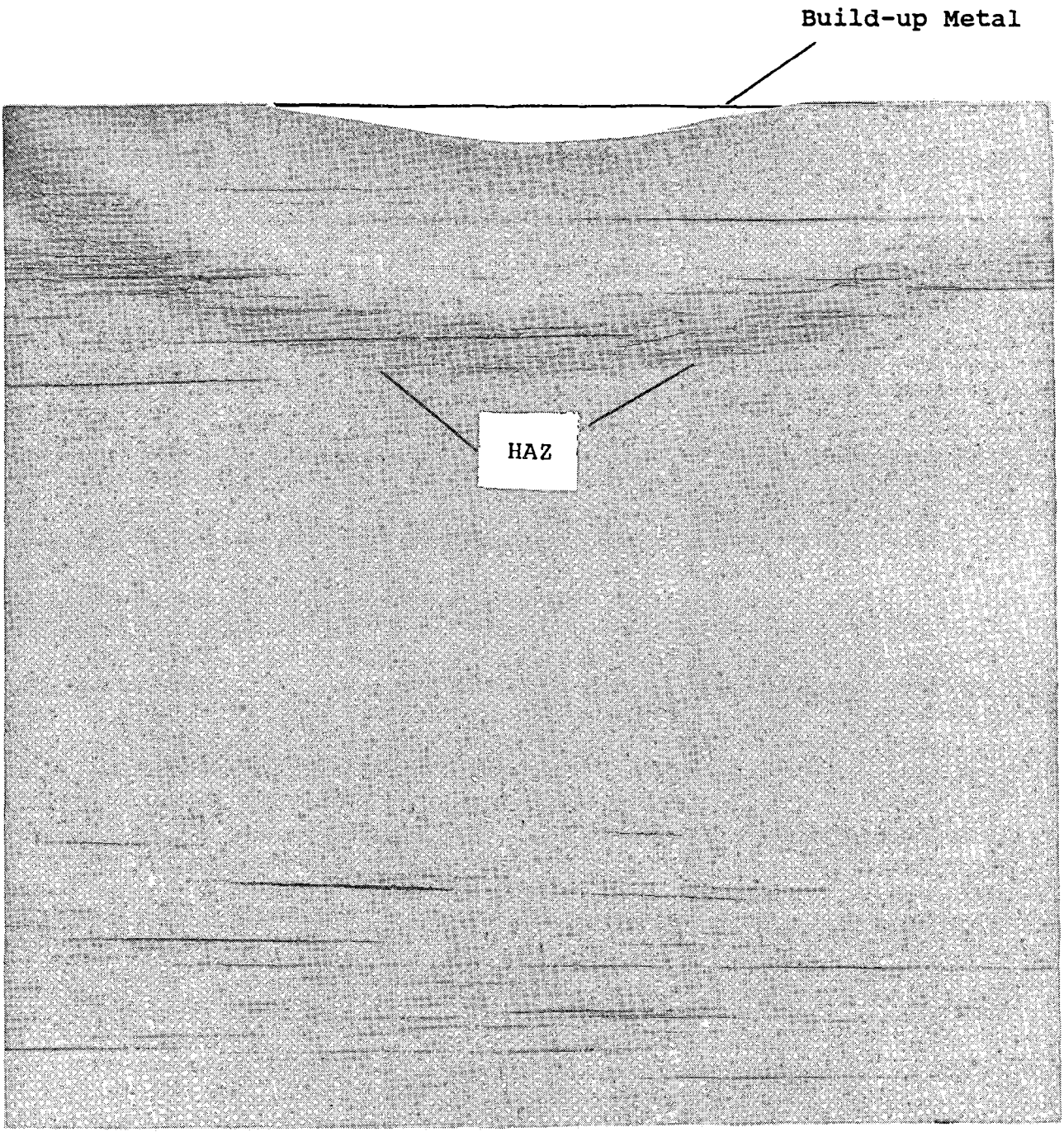


FIGURE B-9. MACROETCH PATTERN OF JNR WELD SHOWING BUILD-UP DEPOSIT AND HEAT-AFFECTED ZONE

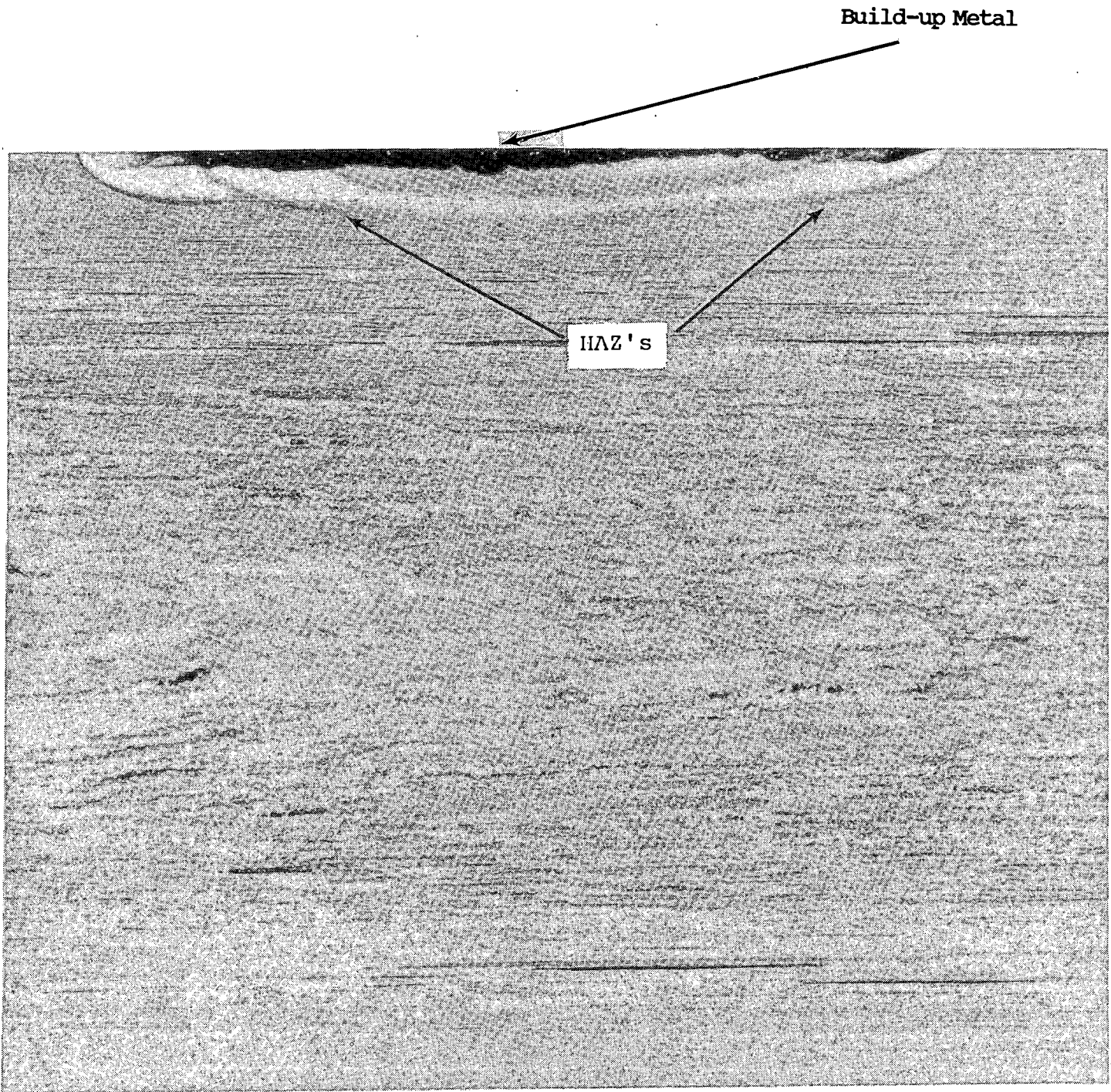
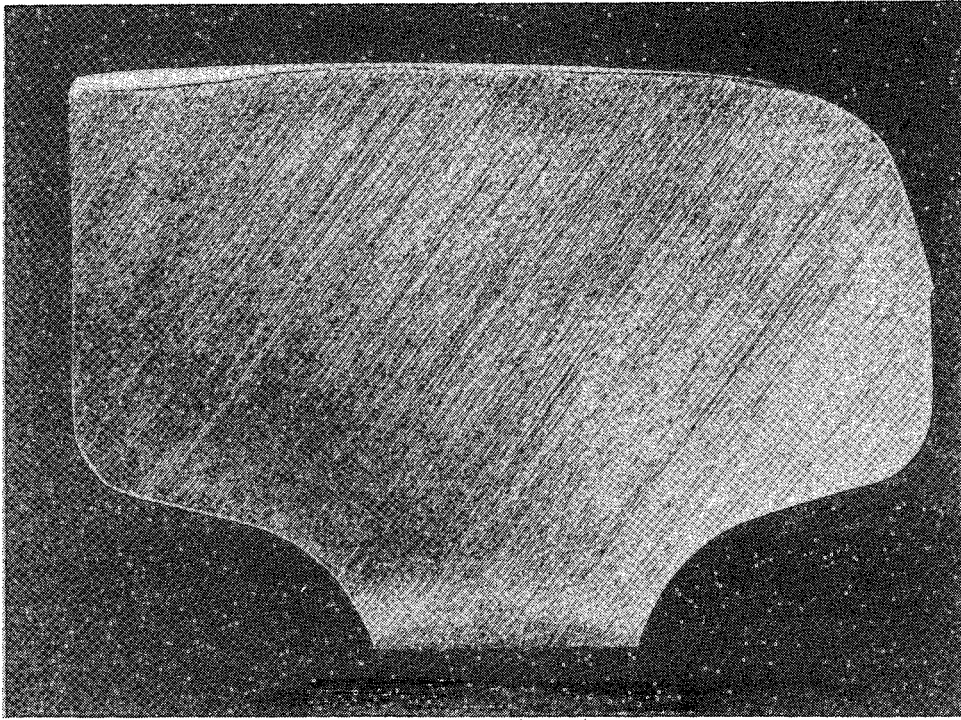
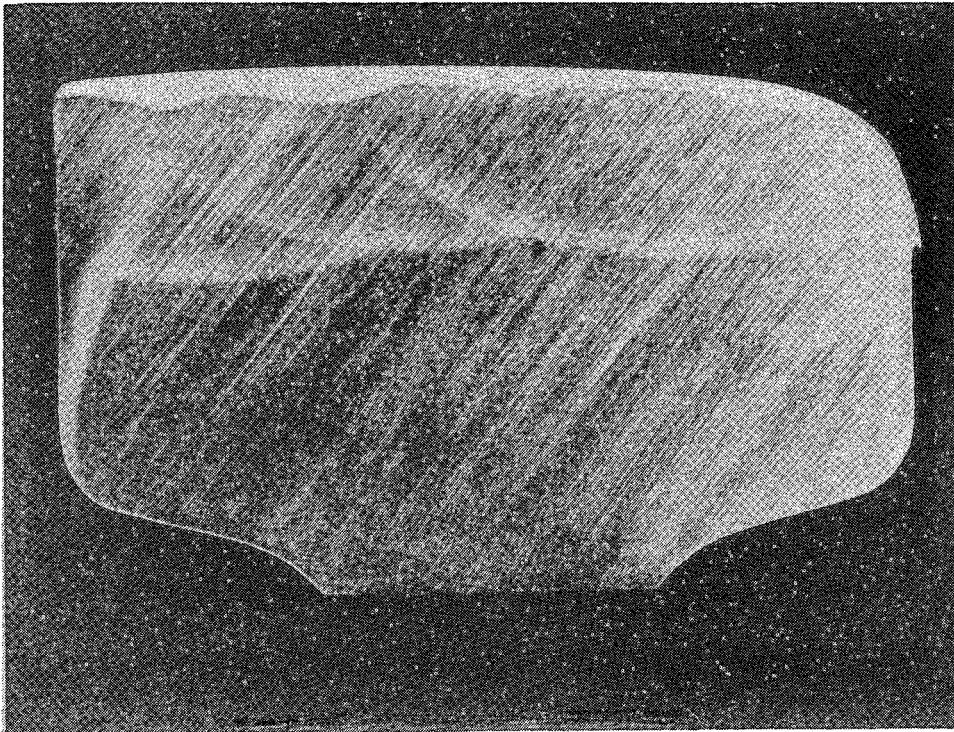


FIGURE B-10. MACROETCH PATTERN OF TTC WELD SHOWING BUILD-UP DEPOSIT AND HEAT-AFFECTED ZONE



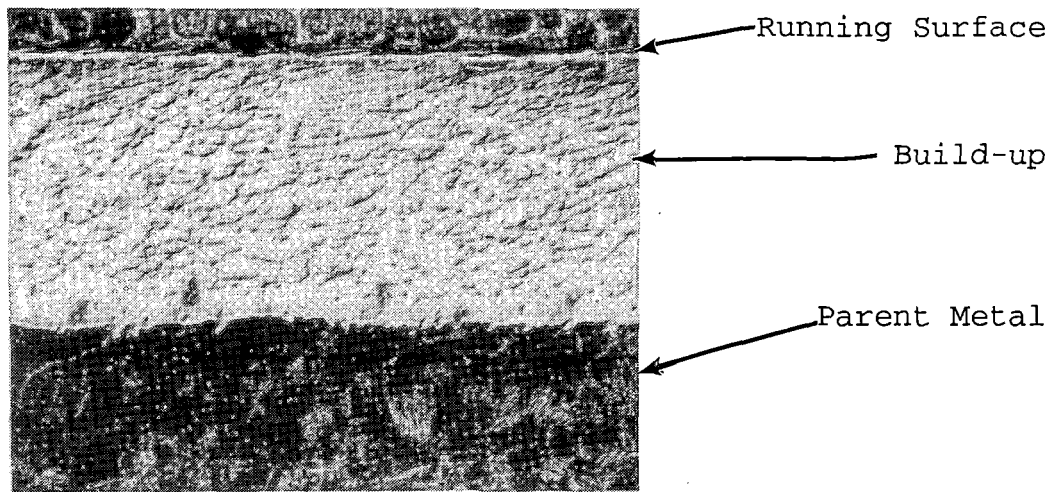
JNR



TTC

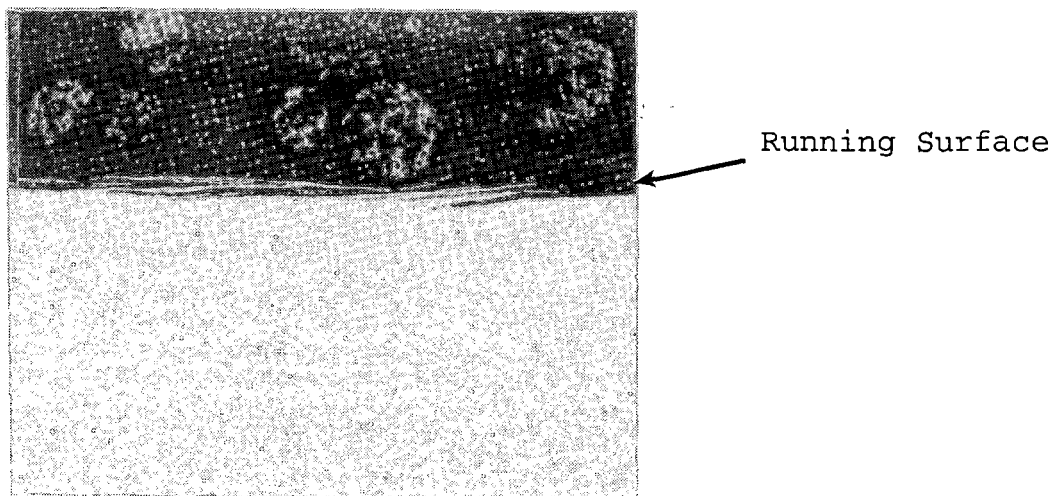
FIGURE B-11. MACROETCH OF TRAVERSE SURFACE OF JNR AND TTC SAMPLES





12a

50X



12b

200X

**FIGURE B-12. MICROGRAPHS OF JNR SHOWING OVERALL VIEW OF BUILD-UP AND PARENT METAL 12a, AND CLOSE-UP OF RUNNING SURFACE, 12b**

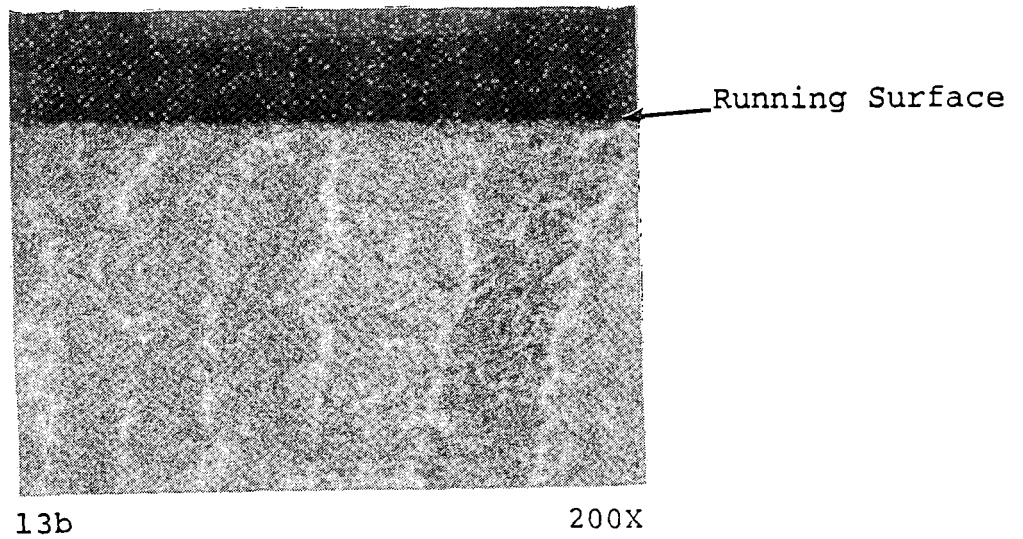
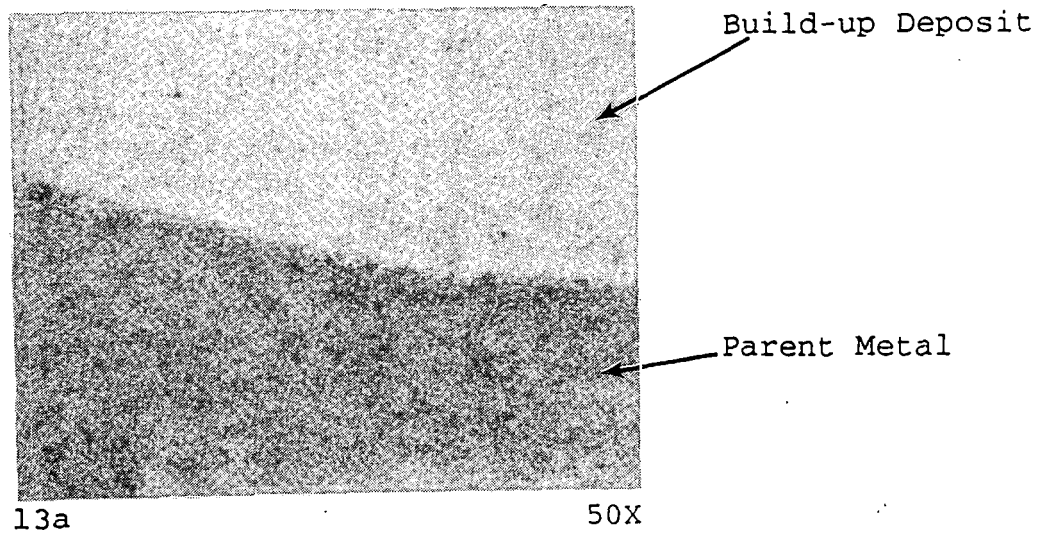


FIGURE B-13. MICROGRAPHS OF TTC WELD DISPLAYING OVERALL 13a, AND CLOSE-UP VIEWS OF THE RUNNING SURFACE, 13b

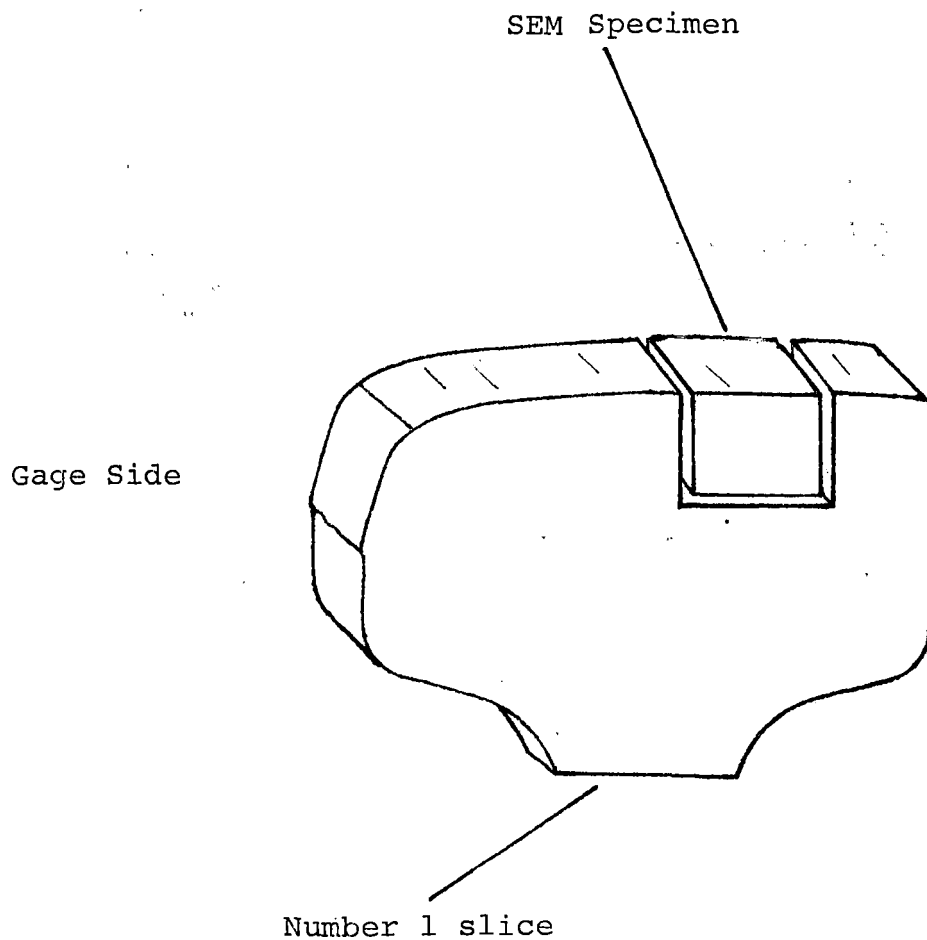
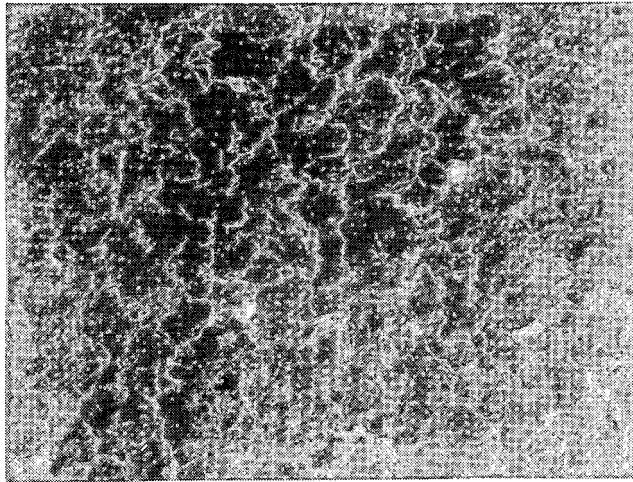
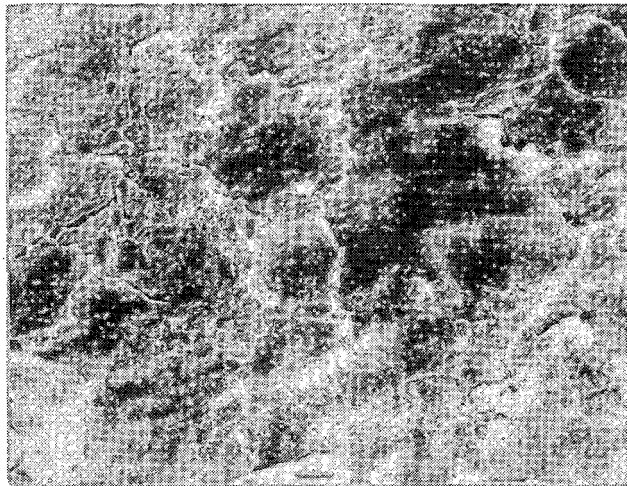


FIGURE B-14. SPECIMEN USED FOR SCANNING ELECTRON MICROSCOPY TEST FOR THE JNR AND TTC WELD SAMPLES



15a

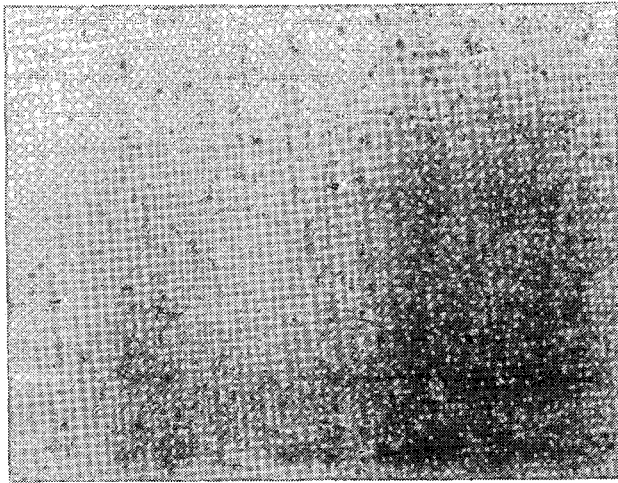
50X



15b

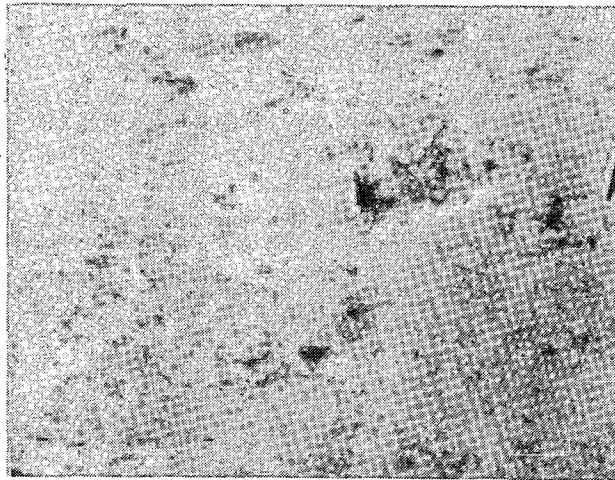
130X

FIGURE B-15. SCANNING ELECTRON MICROGRAPHS OF THE RUNNING SURFACE OF THE JNR WELD



16a

50X



16b

850X

FIGURE B-16. SCANNING ELECTRON MICROGRAPHS OF THE RUNNING SURFACE OF THE TTC WELD

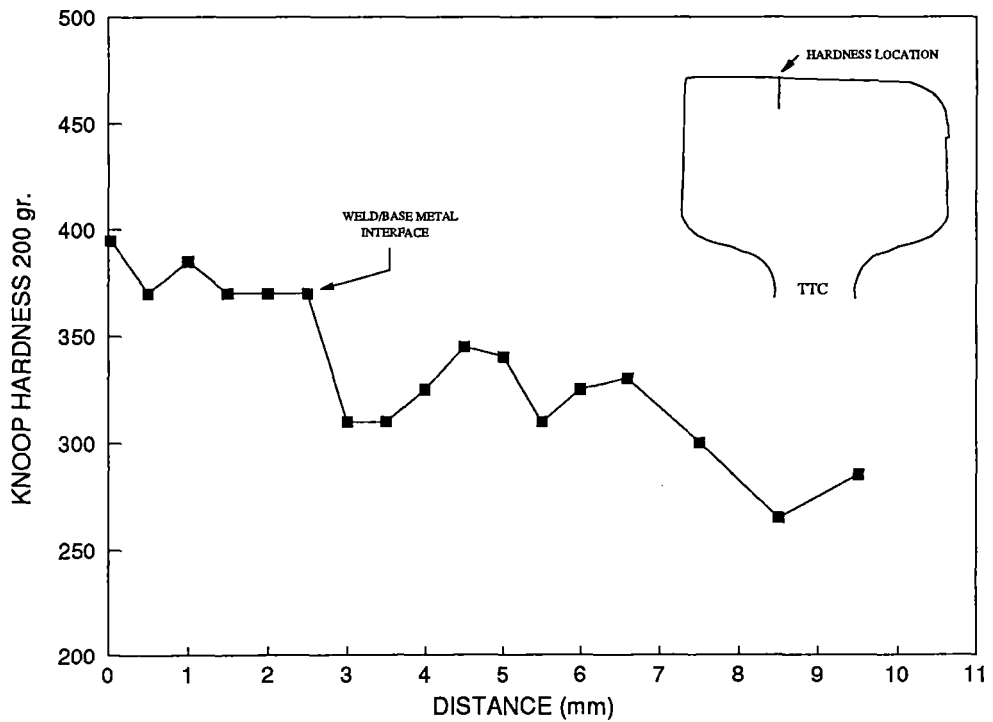
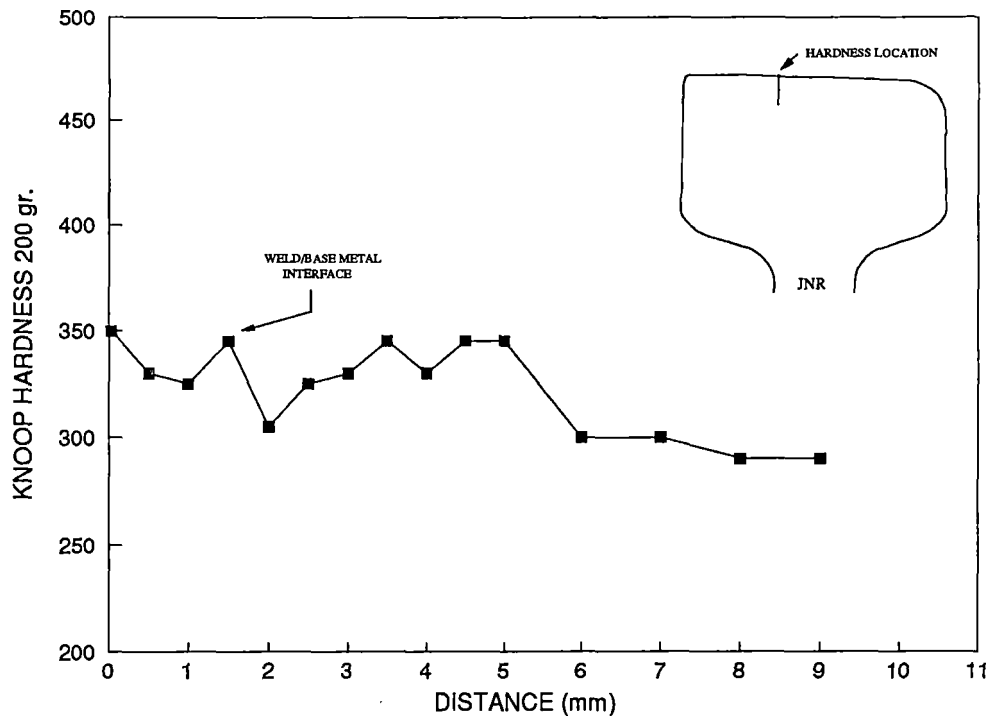


FIGURE B-17. MICROHARDNESS COMPARISON OF JNR AND TTC WELDS

APPENDIX C

CONVENTIONAL ELECTRIC-ARC  
RAIL REPAIR METHOD USED AT FAST

PROCEDURE FOR THE  
BUILDING-UP OF DEEP CHIPS, SMALL DEFECTS,  
SHELLS, OR ENGINE BURNS ON THE GAGE FACE OR RUNNING SURFACE  
OF STANDARD CARBON RAIL\*

January 1985

SAFETY

There are several hazards associated with any track welding operation, and the following protection is required:

1. Protection against train traffic.
2. Protection of eyes and face against flying and hot debris.
3. Protection against shock hazard, especially in wet weather.
4. Protection of skin by wearing proper gloves and clothing.

RAIL IDENTIFICATION AND TEMPERATURE

This procedure shall only be used on standard carbon rail. All other rail metallurgies, as stamped on the web or neutral axis, are not to be built up using this procedure. This procedure is not to be undertaken when (1) rail temperatures are less than 32°F, (2) wind prevents proper preheating and postheating or will blow dirt or sand into the weld area, and (3) moisture in the form of rain or snow could enter the weld area.

\* This procedure presents working rules for a crew rather than a formal description of the procedure.



## PREPARATION

The entire procedure takes approximately one hour to complete. In order to expedite work, the procedure should be implemented without interruption from beginning to end for each repair location. Of particular importance is lost time in the event the rail must be preheated more than once. This is usually caused by the need to remove all equipment and personnel from the track to clear for trains. If the preheating, welding, postheat is interrupted and the rail heat is lost, the heating portion of that part of the procedure must be repeated prior to continuing.

Using an 18-inch, minimum length straightedge, examine for batter and mark the limits of welding. Visually examine the defect area and, if necessary, extend weld limits to take in all defective portions. Generally, build-ups of more than six inches is not recommended as the interpass temperatures are difficult to maintain.

Grind out defect, chip, spalled, or shelly material in the area to be welded. In order to prevent the development of untempered martensite during the grinding, be extremely careful not to overheat or burn the rail with the rail grinder. Remove sufficient metal from the defect area of the rail to eliminate all cracks and damaged metal. Visual inspection is sufficient to detect cracks.

## PREHEATING

Using a No. 20 rosebud tip with oxygen and chem-o-lene or acetylene, preheat the area two inches on all side of the ground-out defect to 1,100°F. After reaching the recommended preheat temperature by oscillating the torch head, soak the railhead for two minutes to assure the interior of the railhead is near this temperature. The web and base should be heated to at least 300°F to 500°F. Determine the temperature by checking the railhead, preferably with a hand-held digital thermometer applied to the

weld limits. To ensure the railhead is at the required temperature, take measurements at the farthest location from the defect, usually on the field side.

Any cracks in the weld area will show as dark lines or streaks on the heated metal surface. If cracks are detected, repeat the grinding procedure above and follow with another preheating.

Caution must be exercised during preheating to protect the eyes from flying debris such as small chips of metal that may pop out of the repair area.

### WELDING

Immediately after preheating, weld the rail using a 7/32 inch M-932 welding rod, or equivalent. The welder is set to 300 amperes DC, reverse polarity.

In order to maintain an 800°F to 1,000°F interpass temperature, change the welding direction after every pass to help maintain a uniform temperature in the railhead. This also may help in the reduction of crater cracks that sometimes appear in rail build-ups. Welding beads should be at least 3/4 inches wide and should overlap the previous bead halfway in order to reduce under-cutting of the new weld material.

When welding near the gage face, e.g., when building-up a shell defect of the rail, a carbon block should be used. This will enable a bead width of 3/4 inches, prevent metal overflow, maintain heat in the bead and rail while welding the gage face, and reduce the amount of finish grinding.

### POSTHEAT

If the mean temperature falls below 800°F after welding, postheat the area 2 inches on all sides of the weld to a minimum of 1,000°F and not exceeding 1,150°F.

## GRINDING

The weld should be surface-ground and finish-ground immediately after postheating and while the temperature is still above 800°F. This is done to prevent development of untempered martensite and grinding stresses in the rail. It should be a complete surface and gage face grinding, returning the rail to its finish dimensions.

## COOLING

The rail should not be allowed to cool from 1,000°F to 300°F in less than 10 to 15 minutes. Should ambient temperature or wind be cooling the weld area too fast, it may be necessary to insulate the rail. If possible, the weld repair and adjacent metal should be inspected ultrasonically after the rail has cooled.

Gas-Spray Repair of Rail Surface Defects

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