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Evaluation of Nitrogen Alloyed Austenitic Manganese Steel for Railroad Frogs

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Summary

Transportation Technology Center, Inc. (TTCI) and the University of Illinois at Urbana-Champaign (UIUC) have evaluated the feasibility of adding nitrogen (N) to austenitic manganese steel (AMS) for frog castings and consumables to weld repair existing frogs. This *Technology Digest* describes results of laboratory evaluations of adding nitrogen to AMS and similar austenitic stainless steels.

The results of the laboratory tests are very promising in that AMS can be significantly strengthened without losing most of the toughness and ductility that make it the material of choice for frogs. AMS frogs under heavy axle loads may have increased maintenance costs and a foreshortening of service life due to the excessive metal flow and surface maintenance associated with the relatively low initial strength of AMS. N-alloyed AMS has significantly higher yield strength. Thus, N-alloyed AMS is technically feasible and provides significant benefits in reducing initial running surface flow and grinding maintenance. This may result in longer service life, if the higher yield strength offsets the loss in ductility. Field trials will be needed to assess this.

Investigation into methods of adding N to castings and weld consumables was conducted. Due to the relatively low solubility of N in steel, a hot isostatic pressing (HIP) process was to introduce up to 1% (wt) to previously made castings. This method appears to be practical for weld consumables and small castings. Additional development may be needed for large castings.

Findings from this work include:

- AMS alloyed with 0.75 to 1.0 percent N will have yield strengths that are 60 to 80 percent higher than conventional AMS, which means less deformation and surface maintenance.
  - A subsequent austenizing treatment can restore some ductility
- N can be added to frogs in the casting process or by using a HIP treatment.
- N can be added to weld consumables either by using a HIP process on the filler rod or by using N in a shielding gas.
  - Lower N content (~0.4%) and lower strength increases (~40% for yield strength) from welding are expected as compared to HIP treatment of castings
  - Ductility, as represented by percent elongation at ultimate strength, will be decreased from 20 percent to ~11 percent

TTCI used production frogs as the source material for the tests done at UIUC. These frogs, which were made to test running surface profile designs, were used for the HIP treatment of castings and weld consumables.

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INTRODUCTION AND BACKGROUND

Railroads spend more than $300 million per year on frog installations and maintenance. The service life of a railroad frog casting is dependent on many factors, including the support conditions for the frog, running surface maintenance and load environment. Previous studies have shown that special trackwork performance is greatly affected by wheel load.[1] HAL traffic can cause AMS castings to flow beyond maintenance limits before they reach a work hardened steady state of deformation and wear. The subsequent weld repair to restore surface height loss begins the process of rapid deformation of virgin metal again. A weld repair material that has higher initial strength will allow the frog to reach stable conditions before maintenance limits are reached.

It is commonly known that adding nitrogen to steel improves its strength and corrosion resistance.[2,3] Most of the previous studies on nitrogen alloying have focused on austenitic stainless steels. Increases of up to 300 percent in yield strength and 40 percent in ultimate tensile strength were reported for nitrogen contents of 0.8 percent (by weight) and 1.0 percent, respectively. Recent work on single crystal AMS has shown that 1 percent N will nearly double the compressive yield strength. Figure 1 shows the effect of nitrogen on yield strength of austenitic stainless steels. These steels are similar to AMS in structure and properties.[4]

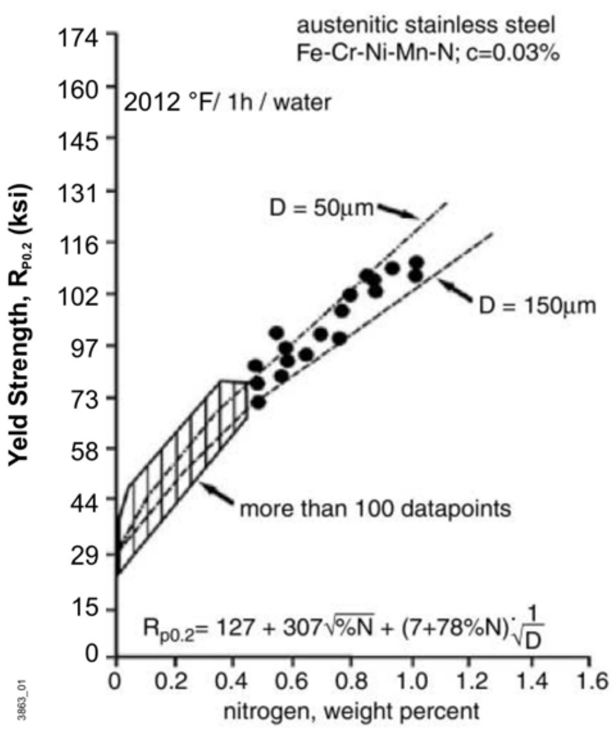

Figure 1. Yield Strength of Nitrogen Alloyed Austenitic Stainless Steel

Stronger and more reliable weld repairs are needed for frogs. As this may be more feasible than treatment of whole frog castings, the work described here focuses on weld repair. Nitrogen alloying during welding has been done for austenitic stainless steels. Nitrogenated filler rods and nitrogenated shielding gases have been used to accomplish introduction of nitrogen in the welding process. For instance, Borst et al. added 0.19 percent nitrogen to a weld region by use of a filler rod and found increased tensile strength and creep resistance in the weld.[5]

MATERIALS AND METHODS

The AMS specimens used in the study were electro-discharge machined from nonworn areas of a frog tested at the Transportation Technology Center, Facility for Accelerated Service Testing (FAST).

A Lincoln Electric Square Wave TIG 255 welder was used to perform all TIG welds. A 1/8-inch-wide weld channel was machined to approximately 90 percent of specimen thickness to preserve base metal alignment for subsequent mechanical testing.

Nitrogen was introduced to the welds by two methods. The first method used a filler metal that had been nitrogenated. This was done using a HIP treatment at 2192°F (1200°C) and 2327°F (1275°C) under 17 kpsi for 3 hours. The nitrogen concentration of the filler metal after these treatments was 0.75 and 1.0 weight percent, respectively. The welds were made with these filler rods using a pure Argon shielding gas. The second method used a shielding gas that had 90-percent argon and 10-percent nitrogen. The filler metal and base metal were both AMS with no previous nitrogen alloying.

The welded specimens were then machined to provide uniform thickness, remove stress concentrations, and produce dog-bone shaped tensile test specimens. The specimens were tested in a MTS servohydraulic frame. Strain was measured in the welded region of the specimen with a miniature MTS extensometer. Figure 2 shows a specimen in test.

Figure 2. Weld Specimen in Test with Extensometer Attached

CONCLUSIONS

An increase in yield strength of approximately 60 percent and an increase in ultimate tensile strength of 25 percent were accomplished using nitrogen treated filler rods and nitrogen added shielding gas. The authors recognize that the first method is more compatible to current frog repair practices. Figure 3 shows the results of the laboratory welding tests.

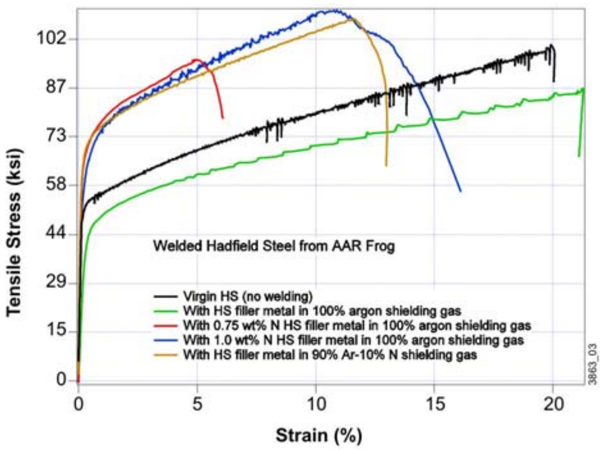

Figure 3. Stress-Strain Response of Welded AMS

Note that welding with either 0.75- or 1.0-percent nitrogen filler rods resulted in about the same yield strength. The differences in ductility are attributed to flaws in the welds.

AMS frog castings from HAL tests were used for the laboratory experiments. Test specimens were machined from locations of the frog that did not see any loading, such as the heel portions of the wings.

Microstructural analysis of the virgin specimens shows they were typical AMS with 1.1-percent carbon and 12.4-percent manganese. Nitrogen was not detectable. The same analysis of the welded specimens shows they have 0.2- to 0.4-percent nitrogen. This is comparable to the solubility limits of the melt in FeCr alloys in the literature.

Figure 4 shows a representative optical micrograph of the welded and deformed region. Note the dendritic appearance which subdivides the grains into a fine network. Also note what appear to be deformation twins (arrow pointing to thin straight black lines in Figure 4). Analysis of various regions of the weld shows variations in nitrogen concentration, but no nitrides.

In the same way, a HIP treatment can be used to add nitrogen to AMS weld consumables; it could be used to treat entire castings. Figure 5 shows the results of adding 0.75- and 1.0-percent nitrogen with a 2192°F and 17 kpsi. An increase in yield strength of 80 percent was found for the 0.75-percent nitrogen treatment. Ultimate strength was also increased by about 20 percent.

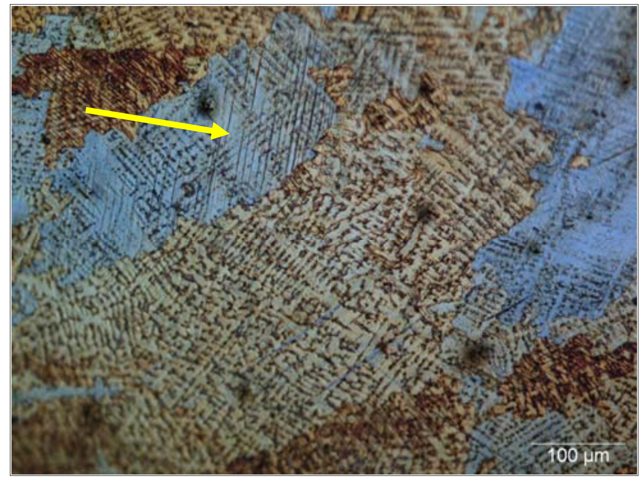

Figure 4. Optical Micrograph of the Weld Region Showing Large Tinted Grains and a Cellular Network

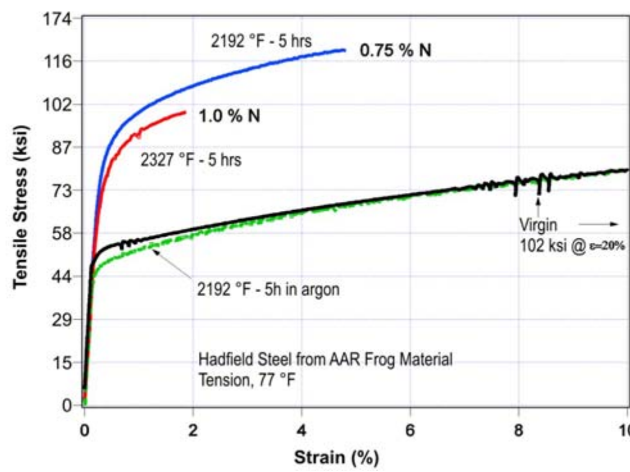

Figure 5. Tensile Behavior of AMS and N-alloyed AMS

A short austenitizing treatment can restore some of the ductility as Figure 6 shows. This treatment does not alter nitrogen concentration, but does reduce yield strength to about 40 percent above conventional AMS.

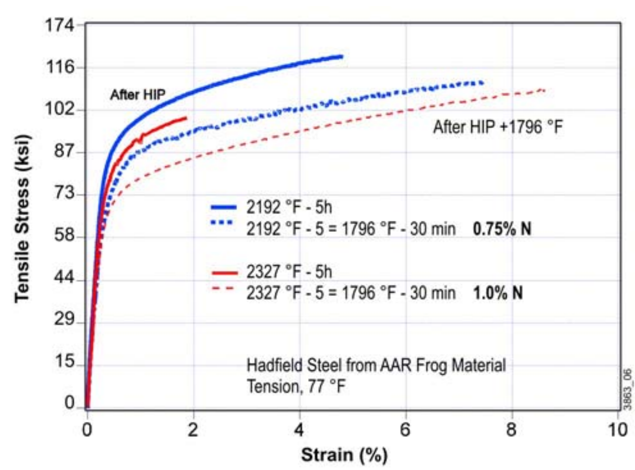

Figure 6. Stress-strain Response of N-alloyed AMS after a Short Austenitizing Treatment

A HIP treatment for mainline frog castings, which are more than 20 feet long, may not be practical. Thus, other methods for N-alloying are being investigated.

FUTURE WORK

Based on the laboratory results, TTCI will seek the assistance of suppliers to develop prototype N-alloyed weld consumables and AMS castings. Field testing is needed to determine if the expected increase in weld or casting strength and expected decrease in ductility will result in a longer service life. These prototypes will be tested under heavy axle load traffic at FAST.

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