Office of Naval Research International Field Office

22. Weldable 800 MPa Class Steel

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March 1, 2002

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Key Words: *Ultrafine grained (UFG) steel, Biaxial rolling processing, Ultra-narrow gap metal gas arc (UNGMGA) welding technique, Pulse modulated laser welding technique, Low temperature transformation weld metals*

1. Summary

A program on weldable 800 MPa class steel, consisting of the development of ultrafine grained (UFG) steel processing and new welding techniques, is underway as a part of the *Ultra Steel* project at the National Institute of Materials Science (NIMS), funded by the Ministry of Education, Science and Technology: http://www.ehis.navy.mil/tp/asia/kameda/Ultrasteel.doc

Ultrafine Grained (UFG) Steel

In order to solve the weldability problem of quenched and tempered (QT) low alloy steel, C-Mn-Si steels not containing alloying elements (Ni, Cu, Cr and Mo) are strengthened by refining equi-axed grains with random orientations. Such steels possess the same weldability as conventionally heat-treated C-Mn-Si steels with the yield strength (σ_y) of 400 MPa. Biaxial rolling below 923 K, where ferrite and austenite phases co-exist, was repetitively applied up to more than 200 % compressive strain to achieve grain sizes < 1 μm. Steel with fine dispersed cementites and grain size of 1 μm, subjected to annealing at 673 K for 1 h, had the σ_y of 750 MPa, the uniform elongation of 10 % and similar fatigue limit (400 MPa) to the QT steel. Charpy V-notched (CVN) tests on the UFG steel indicated the ductile-brittle transition temperature (DBTT) of 130 K with the upper shelf energy of 270 J. UFG (0.5-0.9 μm) steel bars with 18 mm square and 10 m long were fabricated using grooved rolling. Cross rolling process yielded UFG (0.8-1.3 μm) steel plates with 12-18 mm thick, 75-80 mm wide and 1.8-2 m long.

Advanced Welding Techniques

Ultra-Narrow Gap MGA Welding (UNGMGA)

The development of a new metal-gas arc (MGA) welding technology is essential to suppress the grain growth of the heat-affected zone (HAZ) of UFG steels. Advanced welding techniques must meet two requirements: (i) maintain the arc heat as low as possible and (ii) narrow the plate gap (< 5 mm). NISM's new technique utilizes different characteristics of CO_2 welding, which causes deep penetration of molten pools at low welding current, and MIG welding in Ar gas, which produces weld metals with better toughness. CO_2 gas is periodically charged into $Ar/2\%O_2$ atmosphere during ultra-narrow gap MGA welding (UNGMGA). The position of arc tips drops during CO_2 gas charging, which decreases the welding current, while the arc tip rises without CO_2 charging (Fig. 1). A single or double pass UNGMGA welding, applied to 30^o vertex of plates with 12 or 19 mm thick, yielded a HAZ with 2 mm wide and grain size of 4 μm near the fusion line. The mechanical properties of UFG steel butt-welded using UNGMGA welding with 30 kJ/cm were examined. The welded joint failed not in the weld metal but in the HAZ, which was softened by about 8 % due to the grain growth.

Laser Welding

Laser welding has an advantage over the MGA welding in suppressing the grain growth because of the highly localized heat source. However, pores, which act as structural defects, form from keyholes during the laser welding of thick plates. This is a major drawback of laser welding. The mechanism of pore formation has been recently clarified at the Joining and Welding Research Institute, Osaka University and Kawasaki Heavy Industries Inc., and pore suppressing methodologies have been proposed: http://www.ehis.navy.mil/tp/asia/kameda/laserweldFS.doc. A pulse modulated CO_2 laser welding method with 20 kW power has been designed at the NIMS to minimize pore formation. The formation of pores strongly depends on the frequency of laser pulse. Low pore formation occurs at a frequency of 16 Hz, which matches the eigenfrequency of molten metals, while the keyhole is highly disturbed when the laser pulse and keyhole both resonate at the frequency of 100 Hz. CVN tests on laser weld metals of UFG steel depicted a reduction in the DBTT by 50 K, compared to conventional grained steel. A report on the advancement of laser welding technology can be obtained at:
http://www.ehis.navy.mil/tp/asia/kameda/laserweldAP.doc.

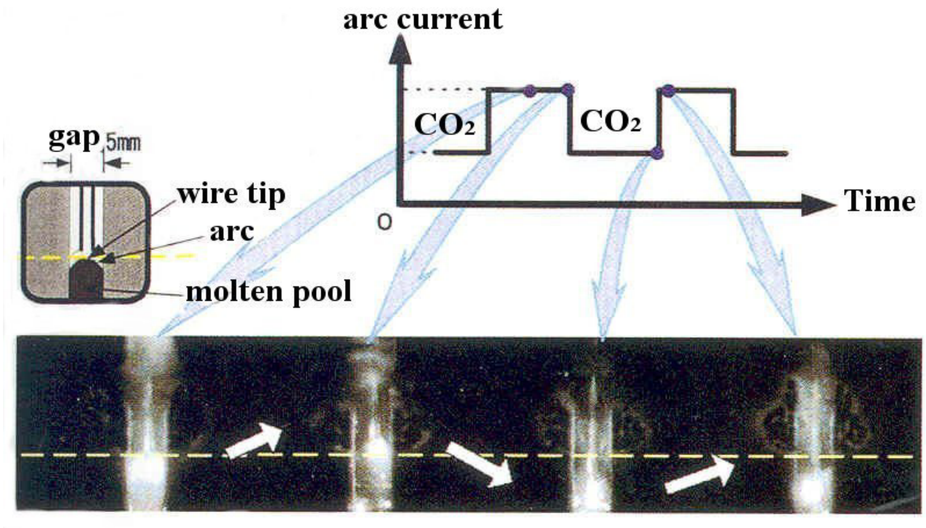

Figure 1. Position shift of molten pool due to the addition of CO_2

Weld Metals with Low Temperature Transformation

Large tensile residual stresses are built-up during welding due to the shrinkage of weld metals and are responsible for lowering the fatigue life of weldment. A new weld metal with low temperature transformation was invented at NIMS. Martensitic transformation below 500 K results in compressive residual stresses near the plate surface due to small contraction at low temperatures. Such weld metals dramatically improve both the fatigue limit by 65% and the cold cracking resistance by suppressing the initiation of cracks.

2. Background

Although this program has applied an approach similar to the *Super Metal* project under the New Energy and Industrial Technology Development Organization (NEDO), weldability is a key issue in the NIMS project:

http://www.ehis.navy.mil/tp/asia/kameda/SuperMetal.doc

http://www.ehis.navy.mil/tp/asia/kameda/UFGS.doc

Other programs of the ultra steel project are reported:

Marine Corrosion Resistant Steel: http://www.ehis.navy.mil/tp/asia/kameda/marinecorr.doc

Ultrahigh Strength Steel: http://www.ehis.navy.mil/tp/asia/kameda/ultra1500steel.doc

Heat Resistant Steel: http://www.ehis.navy.mil/tp/asia/kameda/ultracreep.doc

http://www.ehis.navy.mil/tp/asia/kameda/creepfoldyna.doc

3. Assessment

The weldable high strength steel program is of interest to ONR HQ and Naval Surface Warfare Center, Carderock Division. We are currently exploring the possibility of a cooperative program between NIMS and ONR.

4. Points of Contact

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