FRICTION STIR WELDING OF MA957 OXIDE DISPERSION STRENGTHENED FERRITIC STEEL—S. M. Howard, B. K. Jasthi, and W. J. Arbegast (South Dakota School of Mines and Technology), G. J. Grant, S. Koduri, D. R. Herling, and D. S. Gelles (Pacific Northwest National Laboratory)*

OBJECTIVE

The objective of this effort is to investigate friction stir welding technology for application to oxide dispersion strengthened ferritic steels.

SUMMARY

A 1-in. (25.4 mm) diameter yttria-dispersion-strengthened MA957 ferritic steel alloy tube with a 0.125" (3.18 mm) wall thickness was successfully plasticized by friction stir welding. The pin tool was a W-Re tool with 0.125" (3.17 mm) diameter tip. It showed no discernable wear for the total 12" (305 mm) of weld. Weld conditions were 1000 and 1400 RPM, 4 in/min (101 mm/min), with and without preheating to 135ºC. Metallographic analysis of the post friction-stir welded material showed a decrease in material hardness to 225±22 H_V compared to the parent material at 373±21 H_V. All weld conditions produced plasticization; however, improved plasticization was observed for preheated samples.

PROGRESS AND STATUS

Introduction

In the last 15 years a new joining technology, Friction Stir Joining has emerged that has the potential to join many complex materials. This process, invented by TWI, Ltd.[1], is a solid state process that employs severe plastic deformation to create joints between a wide variety of different materials. The weld is created by clamping the materials to be joined, and plunging a spinning tool into the surface. The spinning tool is then translated down the joint line leaving behind a weld zone characterized by a fine-grained, dynamically recrystallized microstructure. Typically, the tool is spun at 400 rpm to 2000 rpm, and translated down the joint line at a rate of 4 in/min to 300 in/min depending on tool design, base material, and thickness. As the tool rotates and translates, complex flow patterns develop in the base material that creates an intimate mixing of materials from both sides of the weld. Heat input during plastic deformation generally creates a temperature in the weld between 0.6 and 0.8 of the absolute melting temperature, so no liquid phase is generated.

The objective of this investigation is to determine if MA957 oxide dispersion strengthened (ODS) ferritic steel could be plasticized by friction stir welding. MA957 is a commercial yttria (Y_2O_3) dispersion-strengthened ferritic steel alloy that represents the class of oxide dispersion strengthened alloys that may be used as advanced ferritic steels for first wall applications. Conventional welding of such materials disturbs the extremely fine oxide particles within the alloy, because the less dense particles rise to the surface of the molten weld pool. A means for joining such alloys that preserves the dispersion and its concomitant properties would extend the alloy's usefulness and offer important additional applications. One method by which the alloy might be joined while preserving the dispersion structure is friction stir welding. Since fiction stir welding is a solid phase technique for joining metals and alloys, the problem of dispersoid rising to the weld pool surface in fusion welding might be avoided. The primary advantage of friction stir welding of steels compared to most other welding techniques is the lower heat input and avoidance of the liquid-to-solid transformation. This creates less severe metallurgical changes in the weld's heat affected zone (HAZ), less residual stress, and avoidance of problems arising from hydrogen embrittlement and gas entrapment.

The material used for this study was from the National Cladding and Duct Materials Development Program material stockpile. A batch of MA957 bars was purchased for fabrication into fuel cladding[2],

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and one gun-drilled bar remained. It was decided that that bar could be used for initial friction stir joining studies.

Experimental Procedure

The material used in this work consisted of an MA957 cylinder 1.00" (25.4 mm) OD, 0.75" (19.0 mm) ID and 9" (229 mm) length. It was fitted tightly with an Inconel 625 rod as shown in Fig. 1. This ODS MA957 steel clad bar was friction stir welded according to the selected processing parameters shown in Table 1. The processing included with- and without-preheating to avoid a possible ductile-to-brittle transition temperature which is near room temperature for this alloy. The rod was clamped into a V-groove fixture as shown in Fig. 2, but no attempt was made to restrain the material radially as is possible naturally in the welding of a flat plate. Therefore, considerable flash was expected on either side of the weld as well as poor backfilling of the pin tool track. Even so, a determination of plasticization extent was believed possible by this arrangement. The pin tool used was a W-Re tool with 1/8" tip. The specimen was preheating using a hot air gun. Hardness measurements were performed on the completed specimens in selected zones using a Vickers hardness tester. Each weld was approximately 3 inches (76.2 mm) long. After the four welds were completed, the resulting friction stir processed cylindrical specimens were sectioned perpendicular to the axis with water cooling. The samples were mounted and polished for metallographic examination. An etching solution of 2 g $CuCl_2$, 40 ml HCl, and 40-80 ml ethanol was used.

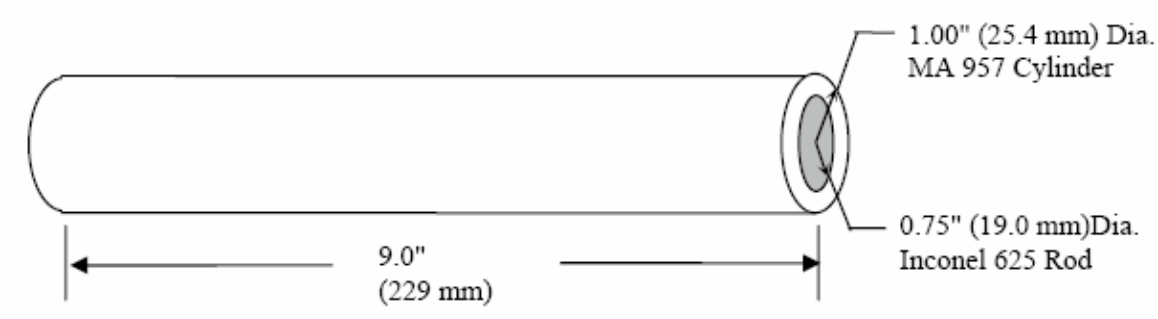

Fig. 1. Dimensions of MA957 ODS steel specimen.

Table 1. Weld process parameters

Weld No	Weld Speed in./min. (IPM)	Spindle speed (rpm)	Condition
1	4	1400	No preheating
2	4	1000	No preheating
3	4	1400	Preheating (135°C)
4	4	1000	Preheating (135°C)

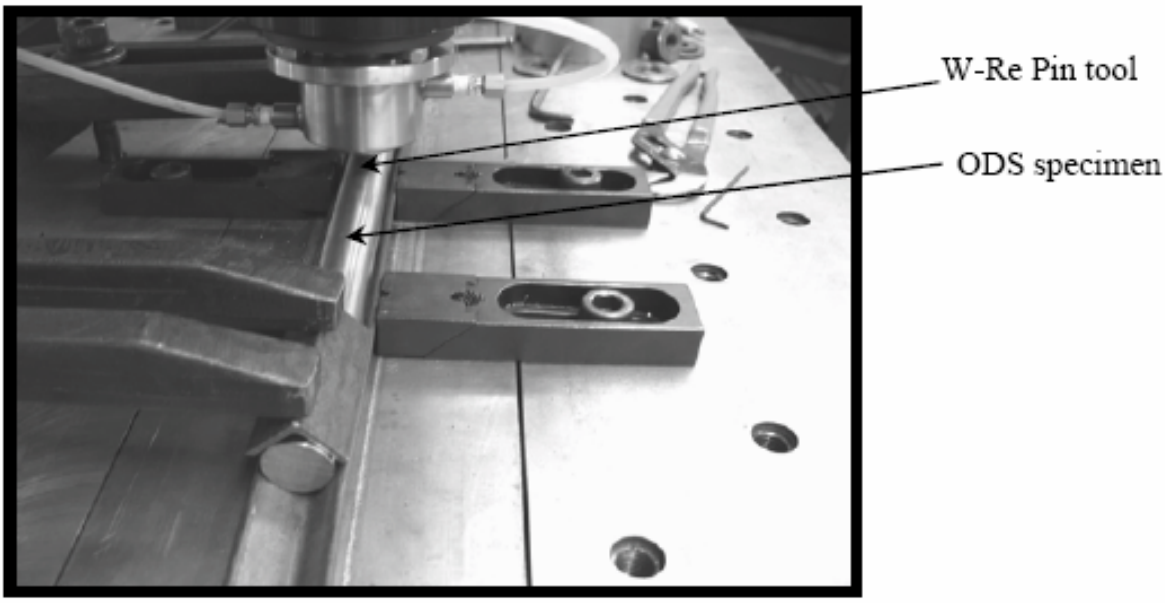

Fig. 2. Friction stir welding setup for MA957.

Results

Plasticization was achieved for all weld conditions. The W-Re pin tool showed no noticeable damage or wear; however, some ODS MA957 metal adhered to the pin tool. Figure 3 shows plasticized material in the processed region. The processed region is not consolidated due to tool-part mismatch arising from the tube curvature. However, the plasticized region shows the nature of flow and confirms that ODS alloys can be processed using friction stir welding. Figure 4 shows micrographs of the parent and the nugget zones created by friction stir welding. All of the figures are at the same magnification and have a size bar that is 200 microns in length. Hardness measurements of the plasticized, parent, and HAZ materials are provided in Table 2. Some of the measurements are averages. The table also shows the number of measurements included in each average (#) and the corresponding standard deviations. The results demonstrate that the hardness is reduced by friction stir welding from 373±21 H_V for the parent material to 225±22 H_V in the nugget and ~317±11 H_V in the HAZ.

All welding conditions resulted in considerable plasticity of the ODS MA957 alloy. This work largely dispels concerns that a dispersion-hardened material such as MA957 cannot be plasticized by friction stir welding. It remains undetermined if friction stir welded ODS material retains its valued mechanical properties. However, the hardness measurements do offer some information worth summarizing here.

It was observed that the degree of plasticization was greatest when the material was preheated (to 135°C) and welded at 1400 RPM. Also, higher rotational speed resulted in more plasticization regardless of preheating. Hardness measurements indicated a significant decrease in the plasticized zone compared to the parent material. Furthermore, the nugget hardness is directly related to the weld pitch as shown in Fig. 5. Weld pitch is likely related to the weld temperature, in which case the nugget hardness is directly related to weld temperature.

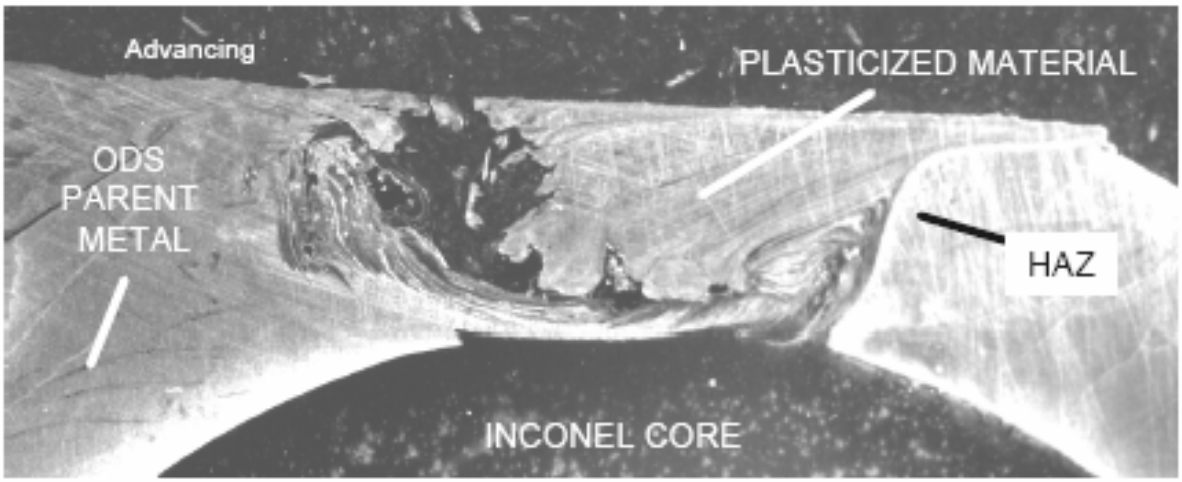

Fig. 3. Cross section of ODS alloy tube plasticized by friction stir processing. Processed region is not consolidated due to tool-part mismatch, but the plasticized region shows the nature of flow and confirms that ODS alloys can be processed using FSP.

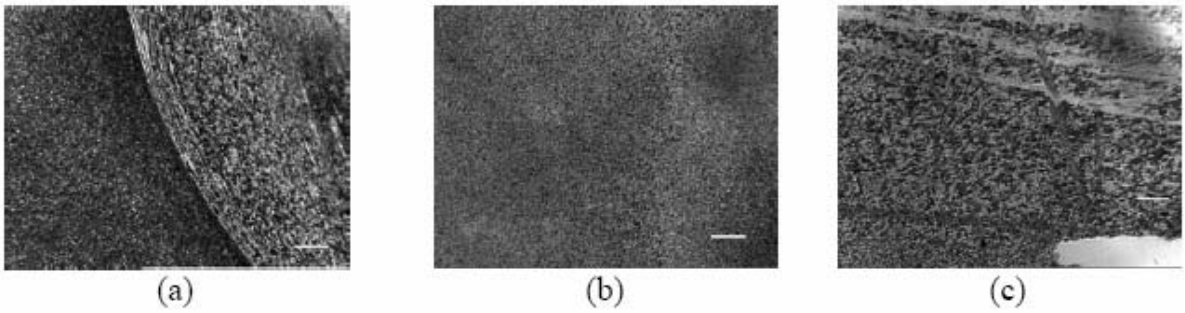

Fig. 4. Micrographs of ODS MA957: (a) nugget (right)-TMZ interface, (b) parent, and (c) nugget zone.

Table 2. Hardness measurements

Weld No	Zone	Hardness, H_V	Standard Dev.	#
1	Nugget	223	17	4
	HAZ	284		1
2	Nugget	240	21	6
	HAZ	339		1
3	Nugget	206	9	3
	HAZ	307		1
4	Nugget	232	25	7
	HAZ	339		1
Parent Material		373	21	4
All HAZ		317	27	4

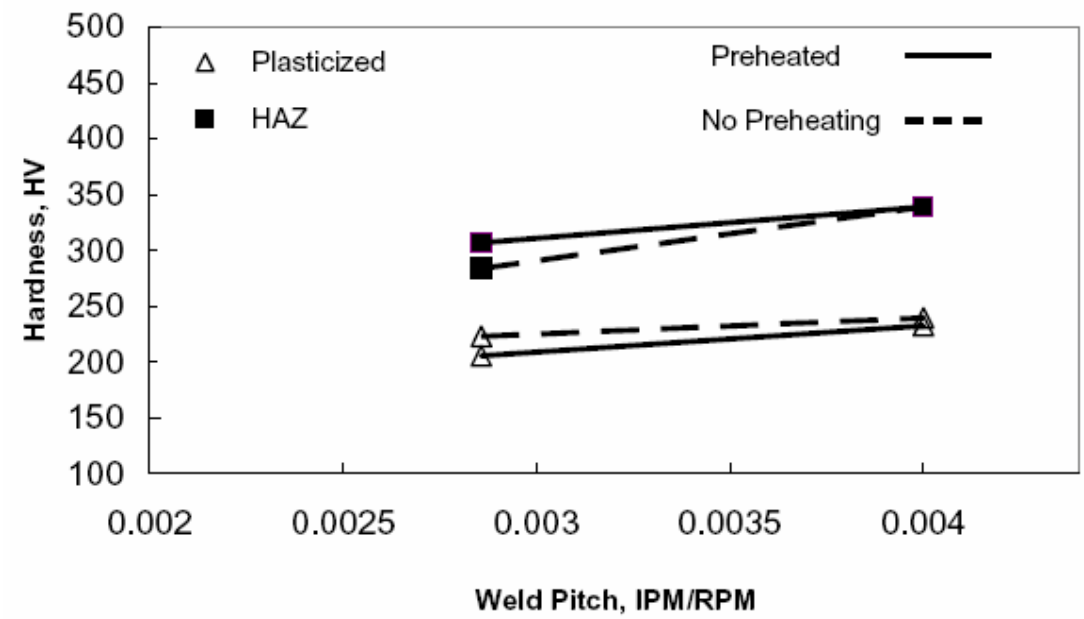

Fig. 5. Dependence of hardness on weld pitch.

Discussion

A decrease in the average weld nugget hardness was observed compared to the parent material from approximately 373±21 H_V to 225±22 H_V. Greater weld pitch, and likely related weld temperature, resulted in more plasticization and slightly greater nugget hardness. No definitive grain size determination was made but morphology suggests an increase in grain size in the nugget. The observed decrease in hardness resulting from friction stir processing may be related to this apparent increase in grain size in the nugget, and is likely is due to yttria redistribution. TEM work is needed to determine the yttria morphology and distribution in the nugget. However, an explanation is possible based on experience with recrystallization of MA957[3], where it was found that hardness was considerably reduced with an accompanying large increase in dispersoid size. The change was attributed to the presence of alumina stringers in the material which allowed replacement of the yttria with a coarser ruby structure. If additional investigation confirms this presumed increase in grain size, one might control such growth by liquid

nitrogen quenching behind the weld. Also, hardness may be regained by doing post weld heat-treatment. However, it may be more beneficial to use alternate material for future work. Unfortunately, ODS ferritic steel in quantities needed for friction stir welding is very limited in availability.

Conclusions

ODS MA957 ferritic steel is plasticized without difficulty when stirred with a W-Re pin tool. Preheating to 135°C improves the plasticization compared to not preheating. Preheating has little effect on the resulting weld. The value of preheating the material above the ductile-brittle transition temperature to prevent pin tool damage was not established.

Future Work

The effort will be continued as opportunities become available.

References

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[2] M. L. Hamilton, D. S. Gelles, R. J. Lobsinger, G. D. Johnson, W. F. Brown, M. M. Paxton, R. J. Puigh, C. R. Eiholzer, C. Martinez, and M. A. Blotter, Fabrication Technological Development of the Oxide Dispersion Strengthened Alloy MA957 for Fast Reactor Applications, PNL-13168 (2000).
[3] M. L. Hamilton, D. S. Gelles, R. J. Lobsinger, M. M. Paxton, and W. F. Brown, Fabrication Technology for ODS Alloy MA957, PNL-13165 (2000) 10.
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