SUMMARY OF THE IEA WORKSHOP/WORKING GROUP MEETING ON FERRITIC/MARTENSITIC STEELS FOR FUSION — R. L. Klueh (Oak Ridge National Laboratory)

OBJECTIVE

The objective of this report is to describe the working group meeting and workshop held to review planned and completed work that is being undertaken to prove the feasibility of using ferritic/martensitic steels for fusion applications.

SUMMARY

An International Energy Agency (IEA) Working Group on Ferritic/Martensitic Steels for Fusion Applications, consisting of researchers from Japan, the European Union, the United States, and Switzerland, met at the headquarters of the Joint European Torus (JET), Culham, United Kingdom, 24-25 October 1996. At the meeting, preliminary data generated on the large heats of steel purchased for the IEA program and on other heats of steels were presented and discussed. The second purpose of the meeting was to continue planning and coordinating the collaborative test program in progress on reduced-activation ferritic/martensitic steels. The next meeting will be held in conjunction with the International Conference on Fusion Reactor Materials (ICFRM-8) in Sendai, Japan, 23-31 October 1997.

PROGRESS AND STATUS

Introduction

The IEA Working Group on Ferritic/Martensitic Steels for Fusion under the auspices of the IEA Executive Committee for the Implementing Agreement on Fusion Materials met at JET Headquarters, Culham, UK, 24-25 October 1996. Researchers from Japan (3), the European Union (4), the United States (3), and Switzerland (1) participated. Russian Federation participation was invited, but no one from there attended the meeting. The objective of the Working Group is the establishment and coordination of an international collaborative test program to determine the feasibility of using ferritic/ martensitic steels for fusion.

This was the sixth meeting of the Working Group, which was formed as a result of a workshop on ferritic/martensitic steels in Tokyo in October 1992. At the first meeting following the Tokyo workshop, the Working Group developed specifications for large heats of reduced-activation steels and outlined a collaborative research program. Two 5-ton heats of the IEA-modified F82H steel and two 1-ton heats of JLF-1 steel were produced, fabricated into plates, and distributed to the participants of the collaboration. Subsequent meetings were used to plan a test program and to coordinate the acquisition of the data needed to prove feasibility for the steels for fusion.

The Culham meeting was a follow up to the meeting at Baden, Switzerland, 19-20 September 1995, at which the first data on the new large heats were presented; the Culham meeting was planned to expand on the review of data on the new heats, since the amount of data generated was expected to increase during the following year. The meeting was also set to review the status and future direction of the programs in Japan, Europe, and the United States in a continuing effort to coordinate the collaborative program.

Research and Development Activities

The first day of the Culham meeting consisted of a workshop on research results obtained on the large IEA heats of F82H and JLF-1 and research results on other ferritic/martensitic steels that have an impact on the objective of the Working Group. A range of properties have been examined for the large modified IEA heats of F82H and JLF-1 reduced-activation martensitic steels. These presentations are discussed in the first section below, followed by a section summarizing the work on other reduced-activation steels and non-reduced-activation steels. A report that includes copies of handouts of viewgraphs used for the presentations is available [1].

Experimental Work on IEA Heats

K. Ehrlich reviewed the studies of nine institutes throughout Europe that had combined to evaluate the homogeneity of chemical composition and mechanical properties of the plates from the IEA F82H heat. The plates are homogeneous, with little variation in grain size, hardness, and tensile properties through the thickness of the 7.5-and 15-mm plates produced from the large heat (the 15-mm plate is slightly stronger than the 7.5-mm plate). Heat treatment characteristics were determined for the steels in an effort to ascertain how optimum properties can be developed. Included in these studies were determinations of austenitization and tempering behavior, and a continuous cooling transformation diagram was determined. The properties of the IEA F82H steel was compared with other reduced-activation steels and the MANET conventional Cr-Mo steel. The IEA modified F82H heat had better Charpy properties than the MANET, but creep-rupture strength and the yield and tensile strength below 500°C of the IEA F82H were slightly less than those for the MANET. The ductility of the IEA F82H exceeded that for the MANET.

K. Shiba reported on the range of mechanical and physical properties planned and being carried out on the modified IEA F82H heat by JAERI. The planned mechanical properties test matrix includes tensile, creep, Charpy impact, fracture toughness (K_{1c} and J_{1c}), fatigue, and hardness tests. These properties are being determined on the as-heat treated base metal and on weldments; tensile, Charpy impact, and fracture toughness data are also being determined on thermally aged base metal and weldments. The following physical properties are also to be determined: density, specific heat, thermal conductivity, thermal expansion, electrical conductivity, melting point, Young's modulus, Poisson's ratio, and magnetic hysteresis. Much of this characterization work has already been accomplished [1].

Other JAERI studies on the modified F82H were presented by A. Hishinuma. These included studies on the effect of tantalum and titanium on grain size and Charpy impact behavior. There were also studies on radiochemical analysis of impurities in the steel, vacuum properties (gas desorption), and corrosion behavior in high-temperature water. The corrosion tests were at 250 and 280°C and showed the effect of dissolved oxygen on the behavior.

D. S. Gelles reported on mixed-mode fracture toughness of the modified IEA F82H and compared the results with previous results reported in Baden on a small heat of F82H with a different heat treatment. The previous results indicated that there was an effect of crack angle, and the toughness in the mixed mode is less than for either Mode I or Mode III. The IEA heat gave similar results for Mode I fracture toughness tests, but there were differences for mixed-mode I/III for the two materials. Tests are continuing to determine the cause of the differences.

P. Spatig reported on a program to study the effect of helium on the properties of the IEA F82H. To determine hardening effects, helium is to be injected into tensile specimens in either the PIREX facility in Switzerland or the duel-ion beam in Karlsruhe. For comparison, pre-injected specimens will be irradiated in the Studvik reactor in Sweden. Specimens irradiated in PIREX have been tested, and specimens are presently being irradiated in the Studvik reactor. Spatig also discussed studies under way to determine activation volumes for irradiated specimens using stress relaxation tests.

A. Kohyama reported on the extensive studies of the large heats of the JLF-1 steel. Just as is the case for the F82H, Monbusho researchers have conducted a range of microstructural and mechanical properties studies on the base metal and on TIG and EB weldments. Tensile, Charpy impact, and creep tests were conducted.

In general, the results of these tests indicate that the new IEA heats have properties comparable or better than those of the commercial steels they would replace.

Experimental Work on Other Heats of Steel

Several reports concerned information gathered on irradiated properties of other heats of reduced-activation and conventional steels, including F82H and JLF-1 heats other than the large IEA heats.

A. Kohyama summarized studies of Cr-W-V steels containing 2.25-12% Cr (including JLF-1 and F82H) irradiated in FFTF/MOTA. Tensile, Charpy, irradiation creep, and microstructural studies were conducted at 370-600°C and up to 60 dpa. One interesting observation was that hardening, as measured in a tensile test, appears to go through a maximum with dose, which was also reflected in the shift in the transition temperature of the Charpy tests.

D. S. Gelles reported Charpy impact data for PNNL reduced-activation steels containing 2-12% Cr and different levels of manganese irradiated to 10 and 30 dpa in FFTF/MOTA at ≈370°C. There was no change in properties between 10 and 30 dpa. Manganese additions in the 9-12% Cr steels caused a change from cleavage to intergranular fracture. It was concluded that the 7-9Cr steels show the most promise.

K. Shiba reported on the tensile and fracture toughness properties of a heat of F82H irradiated in HFIR over the range 200-500°C. Experiments to asses helium effects using boron doping were also reported. Different levels of ^{10}B were added to F82H, and the steels were irradiated in the JMTR to 0.05-0.6 dpa at 400 and 550°C. No effect of helium was observed on tensile properties, but there appeared to be a slight effect on the Charpy behavior.

A. Kohyama reported on work by Kimura, Morimura, and Matsui of Tohuku University on the effect of helium implantation on the DBTT of a 9Cr-2WVTaB steel. TEM disks were implanted with 120 appm He in a cyclotron at 36 MeV at ≈220°C to 0.048 dpa. A small punch test was used to estimate an increase in yield stress of ≈104 MPa and a shift in the DBTT of ≈50°C. The changes were attributed to the possibility of enhanced hardening by helium.

M. G. Horsten reported on irradiation studies of tensile and fracture toughness measurements of modified 9Cr-1Mo and Sandvik HT9 irradiated at ≈80 and 300°C in the High Flux Reactor (HFR) at Petten. Tensile tests from room temperature to 600°C showed that the high-temperature damage (300°C irradiation) was more stable than low-temperature damage (80°C irradiation). The toughness of the modified 9Cr-1Mo was superior to that of HT9.

R. L. Klueh reported on the tensile and Charpy impact properties of the ORNL reduced-activation steels with 2.25-12% Cr irradiated in FFTF/MOTA to 27-29 dpa. The 9Cr-2WVTa steel continued to show excellent impact properties. The shift in transition temperature was only 32°C after ≈28 dpa, although there appeared to be a slight increase in the shift with increasing fluence. However, even after the 32°C shift, the DBTT after irradiation was lower than the DBTT of modified 9Cr-1MoVNb or Sandvik HT9 before irradiation (these steels showed shifts of ≈45 and 160°C, respectively, for these irradiation conditions).

K. Ehrlich presented the latest Charpy impact data from a continuing irradiation experiment in HFR, in which the conventional steels MANET I and II and the reduced-activation steels OPTIFER Ia and II, F82H, and ORNL 9Cr-2WVTa are being irradiated. Data obtained after irradiation to 2.5 dpa at 300°C were reported; previously, data were reported to 0.8 dpa. The reduced-activation steels again performed better than the MANET steels, and the 9Cr-2WVTa steel again showed the smallest change in Charpy properties.

Fracture Assessment

An integrated approach to assessing fracture-safe margins of fusion power plant structures was presented by G. R. Odette. The types of data on irradiated and unirradiated specimens required to apply the methodology were outlined, and examples of the application of the technique were described. This approach has been formalized in a paper, copies of which were distributed to participants at the meeting.

Collaboration: Planning and Status

On the second day of the meeting, the status and future direction of the programs in Europe, Japan, and the United States were reviewed by W. Dietz, A. Hishinuma, A. Kohyama, and R. L. Klueh, in a continuing effort to coordinate the collaborative program [1].

A major question concerning the use of ferritic/martensitic steels for fusion has concerned the interaction of a ferromagnetic structural material with the magnetic fields of a fusion power plant and how the ferromagnetic material will affect plasma control. Up until now, this question has been addressed by design studies. In his discussion of the JAERI program, A. Hishinuma presented information on JAERI plans for an experimental study of this problem. JAERI will produce a simulated ferritic steel vacuum vessel by covering the inner surface of the vacuum vessel of their JFT-2M with F82H. Using this vessel, they hope to measure the effects of the ferromagnetic material on the operation of the machine. They also have plans for simulating a ferritic steel blanket module. Diagrams of the JFT-2M vessel with the proposed F82H modifications are shown in the attachment.

During the discussion of the proposed JAERI program, it was recognized by the Working Group that a timely assessment of the effect of a ferritic steel blanket structure on the ability to control a plasma is of utmost importance in verifying the feasibility of using ferritic steels for fusion. The program will also provide invaluable information on the development of large-scale fabrication technology of martensitic steels, because the project will require studies on the production of large heats of steel and the welding and joining of large structures. The Working Group and the fusion community will look forward to seeing the results of the JAERI study, because of the important contribution it will make toward our understanding of the martensitic steels for fusion applications.

Areas requiring coordination by the Working Group in the future were discussed. These include work on corrosion and hydrogen embrittlement and on creep-fatigue studies being carried out in the different programs. Action items were recommended on these subjects. In the near future, the Japanese and the European Union programs intend to purchase new large heats for component studies, and they intend to coordinate the specification effort for these heats. The need for a compilation of the data being obtained on the new heats of steels was considered. A data base for F82H already exists at JAERI, and an action item was proposed for investigating the use of this data base by fusion programs throughout the world.

Next Meeting

The next meeting was tentatively set for 3-4 November 1997 in Japan in conjunction with ICFRM-8 (23-31 October 1997). The Japanese delegation suggested that the meeting be held near the site of a Japanese steel plant, so that a tour of the facility could be made, thus providing an opportunity for the group to become informed on the technology of steelmaking to be used to produce ferritic/ martensitic steels for fusion applications.

References

[1] R. L. Klueh, Proceedings of the IEA Working Group Meeting on Ferritic/Martensitic Steels, ORNL/M-5674.