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STEEL TECHNOLOGY PROGRAM

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HEAVY SECTION STEEL TECHNOLOGY PROGRAM

OAK RIDGE NATIONAL LABORATORY

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IRRADIATION INVESTIGATIONS OF THE HEAVY SECTION
STEEL TECHNOLOGY PROGRAM*

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Introduction

Investigations of the effects of fast-neutron irradiation on ASTM A 533, grade B, class 1 steel and weldments are being carried out under the auspices of the Heavy Section Steel Technology (HSST) Program. The objectives are to evaluate the effects of irradiation on the fracture behavior of pressure vessel steels and weldments and vessels fabricated from such steels and weldments, taken singly and in combination with in-service related factors such as fatigue, strain aging, stress corrosion cracking, and possibly other embrittling factors; to validate applicability of the fracture technology developed under other tasks of the HSST program in combination with the additional parameter of irradiation; to obtain valid fracture toughness K_{IC} values at as high a temperature as possible; to determine lower bound K_{IC} values under conditions for which actual K_{IC} measurements are impossible or not feasible; to recommend and develop the part that irradiation should play in carrying out the simulated service tests; and to develop a panacea for the toleration of irradiation as affecting the design of nuclear vessels.

It is not the intent of this paper to present the results and accomplishments under this task activity of the HSST program. Only the program itself as generally reflected in the HSST Program Plan will be outlined.

The Irradiation Effects Task Group

A task group was formed in 1967 to assist in developing and evaluating the research program on irradiation effects. The current members

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of the task group are R. G. Berggren, ORNL; D. A. Canonico, ORNL; W. D. Doty, U. S. Steel Corp.; C. W. Hunter, Hanford Engineering Development Laboratory (WADCO); T. R. Mager, Westinghouse Electric Corporation; J. G. Merkle, ORNL; J. L. Mershon, USAEC; and L. E. Steele, NRL. F. J. Witt serves as chairman of the task group. G. Sievers, Institut für Reaktorwerkstoffe, is a cooperative member.

As a result of extensive discussions among the task group an irradiation effects program was outlined. The irradiation investigations were divided into seven categories as follows: basic data, higher temperature, environmental effects, dose rate, spectrum, surveillance, and simulated service test. Emphasis was placed on the basic data and higher temperature investigations. The main participants in the investigations are Westinghouse Electric Corporation (W), U. S. Naval Research Laboratory (NRL), Hanford Engineering Development Laboratory (HEDL or WADCO), and Oak Ridge National Laboratory (ORNL).

Basic Data Investigations

The basic data investigations are being carried out on standard tensile specimens, Charpy V-notch impact specimens, dynamic tear test specimens and fracture toughness K_{IC} specimens. The scope and status of these studies are outlined in Table 1.

We note that both of the Westinghouse activities (W and WADCO) have emphasized fracture toughness K_{IC} determinations while ORNL and NRL have investigated Charpy V-notch impact behavior. ORNL data include load-deflection curves from an instrumented Charpy machine. In addition NRL has emphasized dynamic tear (DT) tests and comparisons of results among DT and Charpy specimens.

The fluences and irradiation temperature of interest are 1 to 5×10^{19} n/cm², $E > 1$ Mev, irradiated at 550°F. Both longitudinal and transverse orientation are being investigated. Emphasis is on the quarter thickness (or nonsurface) locations. cursory examination at the extremes of the conditions of interest are also being carried out some of which are not reflected in Table 1. Neither are the investigations

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being carried out at Institut für Reaktorwerkstoffe listed in Table 1. This work is summarized in Paper 15 of this conference.

Higher Temperature Investigations

The fracture toughness of the irradiated A 533, grade B, class 1 steel must be determined at higher temperatures if it is to find application to actual engineering problems. In recognition of this K_{IC} is being sought at higher temperature levels by means of irradiating thicker specimens. Irradiation of 2-in.-thick compact tension specimens were recently completed and the specimens tested (see Paper 18 of this conference). Plans for irradiation of 4-in.-thick specimens are well advanced and call for insertion of such specimens in a reactor before July 1971.

Specimen loading conditions (dynamic and arrest) will probably be investigated depending upon evaluations of dynamic and crack arrest toughness on unirradiated material (see Papers 8 and 9 of this conference).

Environmental Effects

This area of investigation involves the combination of irradiation and other environmental conditions. The other environmental conditions include strain aging, warm prestressing, fatigue and crack growth, annealing, and possibly the applicable water environment. Some annealing studies have been completed. Fatigue and crack growth studies will be initiated within six months.

Dose Rate and Spectrum Studies

Since extensive efforts on these activities have been carried out and continue to be carried out, no specific activities are currently anticipated in these areas.

Surveillance

An agreement has been reached with the ASTM E-10 Committee to provide, upon request, surveillance material (HSST plate 02 material) for use as monitor material in operating reactors. In addition it is recognized that much of the surveillance data will probably be from Charpy V-notch impact specimens. The interpretation of these results into meaningful and quantitative fracture toughness values is the basis for Paper No. 3 of this conference. Also, Paper No. 13 suggests an alternative approach to the surveillance problem.

Simulated Service Test

The direct applicability of results from the irradiation investigations to pressure vessels will depend very significantly on how convincing the technology established for unirradiated steel is. This is especially true for applications in the transition region. The research potential here covers (1) irradiation simulation, (2) testing an available irradiated vessel (one removed from service), (3) testing of irradiated specimens (6-in. thick or greater), (4) testing a thick pressure vessel which contains a region of significant irradiation (either by irradiating the vessel or welding in an irradiated sector).

It is hoped that irradiation simulation will prove feasible in order to establish a high degree of confidence in the methods established in other tasks of the HSST program.

General Philosophy

At the current time no additional irradiation experiments are anticipated under HSST sponsorship except for the irradiation of the 4-in.-thick specimens. This comes about mainly from the considerable volume of irradiated material available from irradiated and tested specimens. For instance, there are 16 broken halves of the 2-in.-thick specimens tested by Westinghouse (see Paper 18 of this conference). Each broken half is about 5-in. long, 2.4-in. wide and 2-in. thick. A considerable number

of smaller specimens could be machined from this material. As an example, 32 compact tension specimens about $7/8$ in. thick could be obtained together with many, many Charpy specimens. One may well imagine the smaller specimens obtainable from a broken half of a 4-in.-thick specimen (10-in. long, 4.8-in. wide and 4-in. thick). Thus, the availability of material is not a problem as much as scheduling and obtaining reasonably homogeneous conditions on the larger specimens during irradiation.

Practically all the specimens for the environmental effects study will be obtained from broken halves of previously tested specimens. Assuming the methods discussed in Paper 13 of this conference prove feasible, the broken halves will also provide the specimens from which bounding toughness values will be obtained up to 550°F.

Summary

The extensive irradiation investigations under the auspices of the HSST program are summarized in this paper. More specific details are found in the HSST Program Plan. The activity is, optimistically, scheduled for completion by July 1973. Papers 3, 13, and 15 through 18 of this conference together with their references summarize further the program direction and results.

The basic data investigations are outlined in Table 1 and are essentially completed. Irradiation toughness levels at higher temperatures and in combination with other environmental factors are now receiving the main emphasis. The broken specimens will supply much of the needed irradiated material. It is anticipated that simulation of irradiation behavior will serve to provide a convincing understanding of the behavior of in-service vessels which undergo significant amount of irradiation in the core region.

Table 1. Work Plan Under Basic Data Investigations of Irradiation Effects
on ASTM A 533, Grade B, Class 1 Steel and Weldments

Material Identification	Investigator	Nominal Fluences (n/cm ² >1 Mev)	Irradiation Temperature (°F)	Orientation and Location ^a	Completion Date for Tests			
					Tension	Charpy V-notch	Fracture Toughness, K _{IC}	Dynamic Tear
Plate								
HSST 01	ORNL	1 × 10 ¹⁹	150	Long. S,Q,C	2-1-69	2-1-69		
			150	Trans. S,Q	10-15-69	10-15-69 ^b		
			450	Long. S,Q,C	2-1-69	2-1-69		
			450	Trans. Q	11-1-69	11-1-69		
			550	Long. S,Q,C	2-1-69	2-1-69		
			550	Trans. S,Q,C	6-1-70	NYS ^c		
			650	Long. S,Q,C	2-1-69	2-1-69		
			550	Trans. Q	3-1-70	3-1-70		3-1-70
			150	Long. Q	8-1-69	8-1-69		
			450	Long. Q	4-1-70	6-1-70		
HSST 02	ORNL	1 × 10 ¹⁹	550	Long. Q	11-1-69	11-1-69		
			150	Long. Q	3-1-70	3-1-70		3-1-70
			150	Trans. S,Q	3-1-70	3-1-70		3-1-70
			550	Long. Q	3-1-70	3-1-70		3-1-70
			550	Trans. Q	3-1-70	3-1-70		3-1-70
			550	Long. C	10-1-69	10-1-69	10-1-69	
			550	Long. Q	10-1-69	10-1-69	10-1-69	
			550	Long. S	10-1-69	10-1-69	10-1-69	
			450	Long. Q	FY 71		FY 71	
			550	Long. Q	8-15-69		8-15-69	
W Plate " in.	WALCO	3 × 10 ¹⁹	550	Trans. Q	FY 71		FY 71	
			500	Long. Q	12-31-69			
			550	Long. Q	12-31-69			10-15-70
			550	Trans. Q	FY 71			FY 72
			550	Long. Q	10-1-69	10-1-69		10-1-69
			550	Long. Q	10-1-69	10-1-69		
			550	Long. Q	10-1-69	10-1-69		
			550	Long. Q	10-1-69	10-1-69		
			550	Long. Q	10-1-69	10-1-69		
			550	Long. Q	10-1-69	10-1-69		

Table 1. continued

Material Identification	Investigator	Nominal Fluences (n/cm ² >1 Mev)	Irradiation Temperature (°F)	Orientation and Location ^a	Completion Date for Tests			
					Tension	Charpy V-notch	Fracture Toughness, K _{IC}	Dynamic Tear
<u>Submerged Arc Weld</u>								
HSST 51-B	ORNL	1 × 10 ¹⁹	150	WM	1-15-70	1-15-70		
		1 × 10 ¹⁹	450	WM	12-10-69	12-10-69		
		1 × 10 ¹⁹	550	WM	5-1-70	5-1-70		
	NRL	3 × 10 ¹⁹	550	WM	3-31-70	3-31-70		3-31-70
		WADCO	1 × 10 ¹⁹	450	WM ^c			
	1 × 10 ¹⁹		450	HAZ ^c				
	1 × 10 ¹⁹		550	WM	7-1-70		11-31-70	
	1 × 10 ¹⁹		550	HAZ	9-1-70		11-31-70	
	8 × 10 ¹⁹		550	WM	FY 72		FY 72	
	8 × 10 ¹⁹	550	HAZ	FY 72		FY 72		
<u>W</u> 11 3/4 in. Weld	<u>W</u>	3 × 10 ¹⁹	550	WM	10-1-69	10-1-69	10-1-69	
		3 × 10 ¹⁹	550	HAZ		10-1-69		
<u>Shielded Metal Arc Weld</u>								
HSST 52 ^c								
<u>Electroslag Weld</u>								
HSST 53-F	ORNL	1 × 10 ¹⁹	150	WM	5-1-70	5-1-70		
		1 × 10 ¹⁹	550	WM	6-1-70	6-1-70		
<u>Forgings</u>								
<u>W</u> (European Grade)	<u>W</u>	3 × 10 ¹⁹	550		10-1-69	10-1-69	10-1-69	

^aLong. - longitudinal (LW), Trans. - transverse (WR), S - surface, Q - quarter thickness, C - center, WM - weld metal, HAZ - heat affected zone.

^bQuarter thickness only.

^cNo work currently scheduled.