ON THE EFFECTS OF PRECRACKING TECHNIQUE ON TRANSITION FRACTURE TOUGHNESS VALUES DERIVED FROM SMALL 3-POINT BEND SPECIMENS — M.A.Sokolov (Oak Ridge National Laboratory) and H.Tanigawa (Japan Atomic Energy Research Institute)

OBJECTIVE

The objective of this work is to verify the validity of a new precracking method of small 3 point bend specimens for fracture toughness measurement.

SUMMARY

Small 3-point bend specimens of F82H steel were precracked using the "plate-precracking" and traditional "specimen-precracking" techniques. The "plate-precracking" technique guarantees crack front that is straight and practically perpendicular to the sides for all specimens in the group. The results suggest that the plate-precracked specimens were in higher constraint during the fracture toughness test than in the "specimen-precracked" specimen. However, difference in T_0 value is within statistical scatter of fracture toughness. Additional testing on different materials is needed to validate the effects.

PROGRESS AND STATUS

Introduction

The fracture toughness specimens for irradiation studies within the fusion program are becoming smaller and smaller due to a variety of reasons. Validity of the fracture toughness values derived from these specimens is always a critical issue. Among different types of specimens, 3-point bend specimens are gaining popularity for the transition fracture toughness characterization of bcc alloys mostly because of the convenience of the their geometry for placement within small-volume irradiation capsules. For example, a 18-mm long, 3.3-mm wide, and 1.6-mm thick V-notched bar is currently the specimen of choice within the DOE-JAERI fusion program although it is not the smallest fracture toughness specimen within this program.

For these small specimens, the straightness and perpendicularity of the crack tip are two of the critical validity issues for experimental fracture toughness determination. In fact, the ASTM standard E1921for transition fracture toughness determination spells out the validity requirements for straightness and perpendicularity.

In practice, the specimen should be carefully monitored during fatigue precracking. Sometimes, precracking may start and grow only on one side without any crack initiation on the other side. In such cases, the fatigue cycling should be stopped to try to determine the cause and find a remedy for the asymmetric behavior. Sometimes, simply turning the specimen around in relation to the fixture will solve the problem for a relatively large specimen. However, for small-size specimens such as those described above for fusion irradiation experiments this may not apply. Because of the small size, fatigue precrack length may not exceed even 1 mm and, thus, there is not enough crack length to fix such a problem. Secondly, even if the fatigue crack is symmetrical on both sides, it is very likely that the crack front has characteristic curvatures near the side edges of the crack tip.

Prof. G.R. Odette from UCSB suggested a special precracking technique to ensure proper or, at least, not to decrease, constraint conditions ahead of the crack tip in these small specimens compared to larger specimens. The basic concept of this technique is that instead of precracking each specimen individually, a relatively large plate is fatigue precracked and then sliced and cut by order into individual small specimens. According to Odette, this plate-precracking technique provides a crack that is straight and perpendicular to the sides without any curvature at the sides. For example, a large piece of test material, let's say 25-mm-thick, has a fatigue precrack that may have some curvature along its 25 mm length. However, slicing this piece into several 1.6 mm thick (or smaller depending on the specimen design) portions makes the crack front in each small portion practically straight and symmetrical.

Very often for large specimens, sharp side grooves provide a simple solution to this problem by removing these curvatures and providing additional stress concentration at the side edges to increase constraint. Typically, side groves are 20% of the thickness (10% from each side). But again for small, 1.6-mm thick and smaller specimens, it means that side grooves would be only a portion of a mm in depth. This makes side groves technologically challenging. Thus, the benefit from this technique is questionable for small fracture toughness specimens.

Overall, a concern is that with small specimens these problems with fatigue precracking would be magnified. From this point of view, the plate-precracking technique offers a unique solution for all these problems. The purpose of this exercise was to exam the advantages of this technique in comparison with the traditional precracking techniques using ferritic steel F82H.

Specimen preparation

It was decided to prepare three groups of specimens (18-mm long, 3.3-mm wide, and 1.6-mm thick V-notched bars). One group, named "plate-precracked", would contain specimens precracked by the technique proposed by UCSB. The second group, named "specimen-precracked", would contain specimens precracked individually by the traditional method. The third group named "side-grooved", would contain specimens individually precracked by the traditional method and then 20% side-grooved. The side grooves were made with a broach typically used for the standard Charpy V-notch specimens which has a 45^o angle and 0.25 mm radius. Thus, the root radius of the side grove was larger than the depth of it which diluted the idea of the side groove as the constraint increaser. Instead, such side grooving simply reduced the thickness of the specimens in the vicinity of the crack propagation.

Experimental

All fracture toughness tests were performed at one temperature, -165^{o}C. A total of 11 specimens was tested in the "specimen-precracked" group, 10 specimens in the "side-grooved" group, and 9 specimens in the "plate-precracked" group. All data were treated using the ASTM E1921 master curve methodology.

(a) specimen-precrack (b) side-grooved (c) plate-precracked

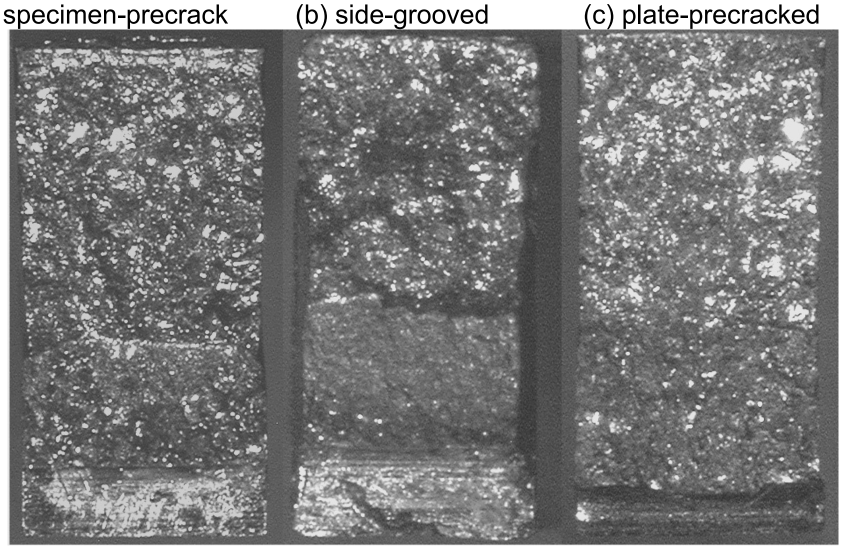

Fig. 1. Optical micrographs of fracture surfaces of a typical specimen from each group tested. Crack propagated from the bottom to the top.

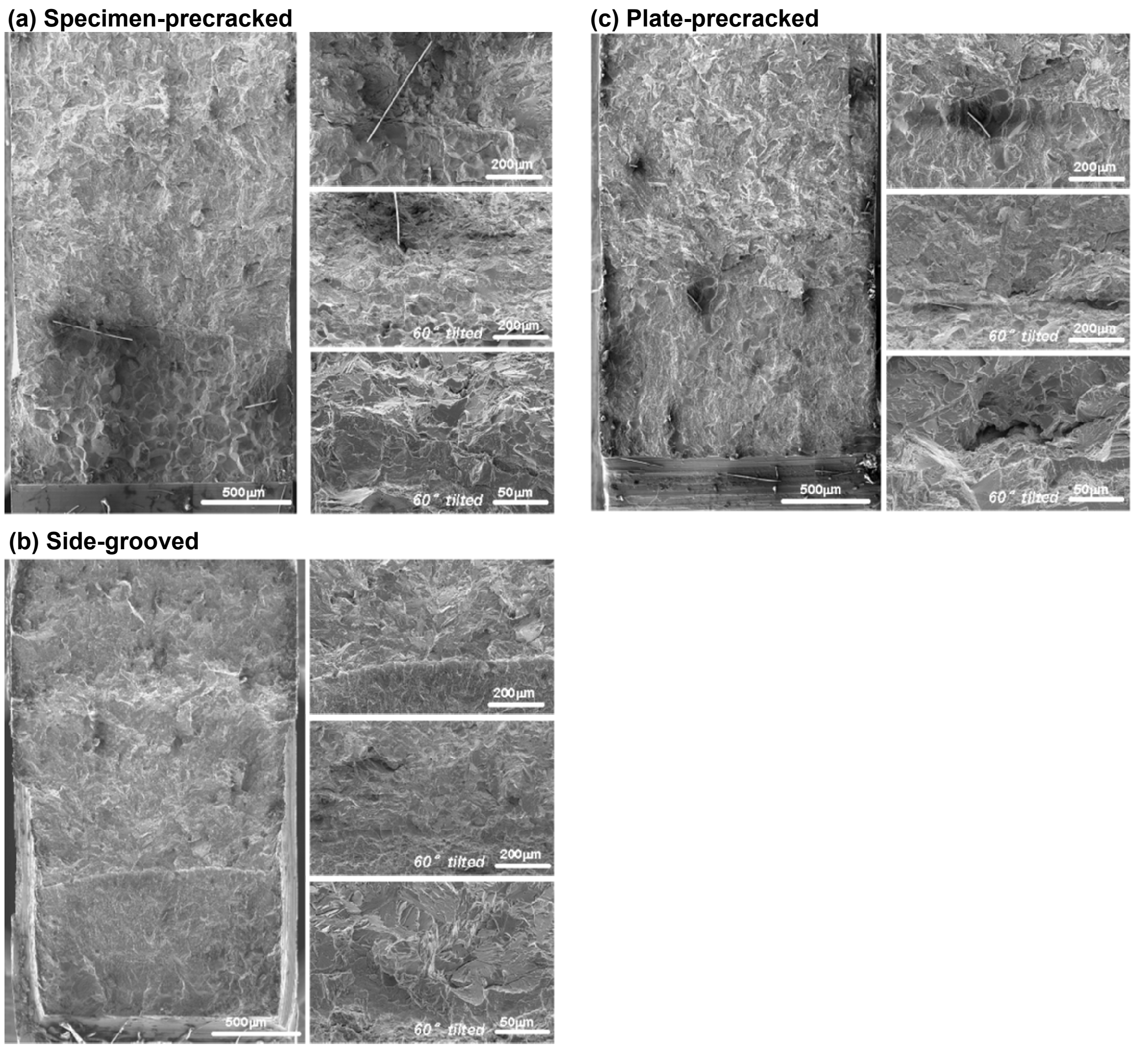

Fig. 2 SEM micrographs of fractured specimen from each group. Right side pictures of each group are the magnified images of fractre initiation points.

Thus comparison can be made in terms of fracture toughness reference temperature, T_o, or $K_{Jc(med)}$.

Results and discussion

Optical micrographs and SEM micrographs of the fracture surface of a typical specimen in each group are shown Fig. 1 and Fig. 2. Tables 1-3 are the tables that contain experimental results, average crack length(a_o) measurements, and results of the master curve analysis for each group examined. Elastic modulus and yield stress used in the calculations are 226GPa and 612.12MPa, respectively.

The master curve analysis shows that the "plate-precracked" group has the highest T_o value (the lowest $K_{Jc(med)}$) followed by the "specimen-precracked" group while the "side-grooved" group has the lowest T_o value (the highest $K_{Jc(med)}$). As discussed above, the highest $K_{Jc(med)}$ value from the "side-grooved" group could be the result of a relatively large root radius used in these side-grooves. In this case, side-grooves could thin the operational region of the specimen instead of providing additional constraint. Thus, the

Table 1. Summary of fracture toughness tests of "plate-precracked" group performed at –165ºC.

I.D.	J_c, kJ/m^2	K_{Jc}, MPa√m	K_{Jc} -1T, MPa√m	$K_{Jc(limit)}$, MPa√m	δ_i	$K_{Jc(med)}$, MPa√m	T_o, °C	a_o, mm	W, mm	a/W
1S	32.81	90.39968436	55.6538469	98.60053648	1	50.4	-99.8	1.412	3.325	0.424662
3S	39.97	99.77709906	60.40302882	98.08375862	0			1.429	3.322	0.430163
6S	31.31	88.30907438	54.59505965	91.82162745	1			1.658	3.317	0.499849
7S	25.92	80.34915198	50.56376523	100.6916002	1			1.32	3.315	0.39819
8S	25.4	79.53909719	50.15351383	95.72373951	1			1.524	3.327	0.45807
9S	27.15	82.2334888	51.51808566	96.88470933	1			1.468	3.315	0.442836
10S	9.49	48.61797938	34.49354588	99.37066432	1			1.359	3.302	0.411569
11S	33.1	90.79831639	55.85573368	99.52397477	1			1.371	3.32	0.412952
12S	7.43	43.01879149	31.657843	101.144828	1			1.307	3.32	0.393675
									AVER=	0.430218
									STDEV=	0.033207

Table 2. Summary of fracture toughness tests of "specimen-precracked" group performed at –165ºC.

I.D.	J_c, kJ/m^2	K_{Jc}, MPa√m	K_{Jc} -1T, MPa√m	$K_{Jc(limit)}$, MPa√m	δ_i	$K_{Jc(med)}$, MPa√m	T_o, °C	a_o, mm	W, mm	a/W
H1	45.21	106.1160443	63.61338105	102.194543	0	54.6	-109.9	1.275	3.317	0.384383
H2	18.19	67.31008646	43.96014407	101.0694312	1			1.32	3.317	0.39795
H3	18.78	68.39299035	44.50857962	99.72802209	1			1.373	3.315	0.414178
H4	22.47	74.81097848	47.75896303	104.8455622	1			1.167	3.317	0.351824
H5	40.91	100.9435418	60.99377252	100.4136206	0			1.346	3.32	0.405422
H6	50.32	111.9525822	66.56928959	101.1950614	0			1.315	3.317	0.396443
H7	26.56	81.33506802	51.06308139	100.5147931	1			1.342	3.32	0.404217
H8	26.22	80.81279779	50.79857817	103.4548788	1			1.224	3.317	0.369008
H9	20.71	71.821397	46.2448926	102.0452449	1			1.281	3.32	0.385843
A11	16.95	64.97535338	42.77772093	98.65206538	1			1.417	3.332	0.42527
H10	71.67	133.6080117	77.53665934	96.35872982	0			1.503	3.317	0.45312
									AVER=	0.398878
									STDEV=	0.027271

Table 3. Summary of fracture toughness tests of "side-grooved" group performed at –165ºC.

I.D.	J_c, kJ/m^2	K_{Jc}, MPa√m	K_{Jc} -1T, MPa√m	$K_{Jc(limit)}$, MPa√m	δ_i	$K_{Jc(med)}$, MPa√m	T_o, °C	a_o, mm	W, mm	a/W
A1	79.45	140.6730001	81.11471535	93.57599025	0	59.7	-119.9	1.609	3.332	0.482893
A2	43.79	104.4362505	62.76265125	101.9206627	0			1.291	3.335	0.387106
A3	34.15	92.22722743	56.57940419	100.8680975	1			1.33	3.332	0.39916
A4	29.31	85.44205951	53.14306295	95.82986342	1			1.528	3.335	0.458171
A5	64.83	127.0725689	74.22679112	95.6440693	0			1.532	3.332	0.459784
A6	26.09	80.61221201	50.69699171	99.6005415	1			1.38	3.332	0.414166
A7	46.35	107.4456081	64.28673724	96.91093337	0			1.482	3.33	0.445045
A8	35.46	93.97950744	57.46684458	97.32955706	1			1.468	3.332	0.440576
A9	93.61	152.695037	87.20326343	95.80334347	0			1.529	3.335	0.458471
A12	25.03	78.95765175	49.85904139	94.68279798	1			1.568	3.332	0.470588
									AVER=	0.441596
									STDEV=	0.031573

effective thickness of this specimen would be less than the nominal and that could lower the size-adjustment value of $K_{Jc(med)}$. From this point of view, the comparison of the “plate-precracked” and “specimen-precracked” groups is straightforward, since both groups have specimens of the same thickness. It is a well known fact that less constrained specimens exhibit higher toughness. The fact that the specimens precracked by the traditional technique exhibited higher $K_{Jc(med)}$ value than the “plate-precracked” group indicates that the “specimen-precracked” specimens might have less constraint than the “plate-precracked” specimen. The difference in the $K_{Jc(med)}$ values of two groups is about 10%. However, it is not clear at this point whether the entire difference can be attributed to the advantages of the precracking technique or it is also part of a scatter in properties.

Summary

Small 3-point bend specimens of F82H steel were precracked using the “plate-precracking” and “specimen-precracking” techniques. It was observed that the “plate-precracking” technique simplifies the precracking process and complicates the machining process in comparison with the traditional precracking technique. In return, however, the “plate-precracking” technique almost guarantees a fatigue crack front that is straight and practically perpendicular to the sides for all specimens in the group. This may result in higher constraint during the fracture toughness test than in the "specimen-precracked" specimen. The present results support this postulate. The “plate-precracked” group of specimens exhibited a lower $K_{Jc(med)}$ value than the traditional group. The difference in the $K_{Jc(med)}$ values of the two groups is about 10%. Additional testing on different materials is needed to validate the effects.