

E06/3

## EVALUATION OF WELDMENT STRENGTH-REDUCTION FACTORS FOR FAST REACTOR COMPONENTS CONSIDERING GAGE LENGTH EFFECT

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### ABSTRACT

Experimental study was conducted on the fatigue strength reduction factor (FSRF) of the weldments for the breeder reactor structural design by focusing on the specimen dimension effect. As the result, it was found that the fatigue strength of the advanced 316SS (316FR) hot TIG welded joint was close to that of base metal, except the cases where the gage length of the welded joint specimen was short. A lower FSRF of weldment will be expected for the actual structures because their representative dimensions are considerably larger than those of the specimen used in this study.

### 1. INTRODUCTION

The weldments are generally the critical portions for the structural integrity of constructions. Design criterion of weldments has been one of the great concerns in the development of liquid metal fast breeder reactor (LMFBR) design code.

There are a few methods to evaluate the strength of welded joints of LMFBR components such as ASME Code Case N-47 and RCC-MR. For instance, according to the ASME Code Case N-47<sup>(1)</sup>, the fatigue life reduction factor is uniformly specified as one-half in terms of endurance life, which is decided based on the typical trend of the experimental data for the transverse welded joint specimens<sup>(2)</sup>. Most of them are small specimens with gage length about 15~30mm. However, since the low-cycle fatigue life of welded joint specimen depends on the specimen size such as gage length and thickness<sup>(3)</sup>, it is important to take into account the size effect to improve the strength evaluation procedure for the weldment and to rationalize FBR component design. This paper experimentally shows that the gage length of welded joint specimen has an effect on weldment strength reduction factor.

### 2. TEST MATERIALS AND TEST METHOD

#### 2.1 Test materials

The materials investigated in this paper were advanced 316 stainless steel plate (316FR, 50-mm thickness) and its weldment. 316FR steel was developed with the view of improving creep strength and ductility for the Demonstration FBR applications by a restricted chemistry version of conventional 316 stainless steel. The same conception was also applied to the development of welding material. The weldment used in this study was manufactured by using a tungsten inert gas (TIG) technique. The chemical compositions of 316FR steel and the weld metal are shown in Table 1.

## 2.2 Test method

In order to study the size effect of welded joint specimen such as thickness and gage length on the fatigue strength, low-cycle fatigue and creep-fatigue tests listed in Table 2 were performed. Figure 1 shows the dimensions of welded joint specimens which were taken transversely to the fusion line. This figure also shows the locations of extensometers for strain control and local strain measurements. As shown in this figure, an extensometer for strain control (E0) was attached so as to include the welding metal. Local displacements were also measured by using additional extensometers, which were attached to the narrow regions, including the welding metal (E1), the base metal far away from the fusion line (E2) and the hardened base metal near the fusion line (E3). Local extensometers E1 and E3 in Fig.1 were only attached to the specimen type B and C.

## 3. TEST RESULTS

### 3.1 Specimen dimension effect on the fatigue strength of welded joint

Figure 2 shows the results of low-cycle fatigue tests of welded joint specimens. The failures occurred in the base metal and at the section more than 10-mm away from the fusion line for all specimens. In Fig.2, solid and dotted lines correspond to average fatigue curves of base metal and welding metal, respectively.

The plotted data in Fig.2(a) are the relationship between number of cycles to failure and total strain range, which is controlled or measured by the extensometer with 15-mm gage length (E0 or E1). It is observed from this figure that the fatigue strength reduction factor (FSRF) of the welded joint,  $K_r$ , is approximately 1.3 in terms of strain range, independent of specimen thickness, in the case of 15-mm gage length. On the other hand, the total strain range of the plotted data in Fig.2(b) takes the controlled value by the extensometer E0 with various gage length. It is found that the fatigue life of welded joint specimens depends on the gage length. The thickness in Fig.2(b) changes with the gage length at the same time, but as the thickness effect is not observed in Fig.2(a), the size effect in Fig.2(b) can be principally considered as the gage length effect.

Figure 3 shows the relationship between fatigue life and gage length of welded joint specimen, which is also compared with the average fatigue life of base metal. It shows that the fatigue life of welded joint specimens is improved and becomes closer to that of base metal as the gage length of welded joint specimen increases.

The gage length effect mentioned above is also observed for the creep-fatigue data of the welded joint specimens as shown in Fig.4. The creep-fatigue life of the welded joint specimen with the longer gage length (50mm) is almost the same as the base metal life; on the other hand, the welded joint data of 15mm gage length, widely used in the material tests, are reduced to about half of base metal life.

### 3.2 Local strain behavior of welded joint

For the fatigue and creep-fatigue tests of the welded joint specimen, local strain measurements were performed in the manner shown in Fig.1.

Figure 5 shows an example of the local strain behavior in each portion. In the early cycles, remarkable strain concentration occurs in the base metal far away from the fusion line (E2), but the strain ranges in the vicinity of a weld (E1 and E3) are smaller than the controlled value. The differences of these local strain ranges diminish and each strain range closes to the control value with increasing cycles; however, the higher strain range is kept at the base metal far away from the fusion line, during the whole life. This observation, hence, indicates that the strain concentration occurs in the base metal far away from a weld rather than in the vicinity of a weld. It is also consistent with the experimental results showing that the failures occurred at the section in the base metal and more than 10-mm away from the fusion line.

#### 4. DISCUSSION

Figure 6(a) illustrates the strain distribution in the welded joint specimen based on the local strain measurements as shown in Fig.5. In the case of 316FR TIG welded joint, since the material in the vicinity of the weld is locally harder than the base metal surrounding the region, the average strain in the gage length including the weld increases with the increasing of the gage length and finally reaches the strain level of the base metal. Therefore, the fatigue strength of the welded joint specimen is improved and approaches the base metal curve with the increasing of the gage length as depicted in Fig.6(b).

In the design of LMFBR components, the weldment should be located away from the region where a remarkable strain concentration caused by the structural discontinuity will occur, so the "effective" gage length of actual structures seems to be considerably longer than that of the specimen used in this study. Therefore, for the weldment in the actual components, no or much smaller fatigue strength reduction will be expected than the experiments obtained by the small test specimen.

#### 5. CONCLUSIONS

The fatigue strength reduction factor for advanced 316SS TIG welded joint was experimentally studied by focusing on the specimen dimension effect. The results obtained are summarized as follows:

- (1) The fatigue reduction factor of the welded joint was about  $K_f=1.3$  in terms of strain range for the specimen with 15mm gage length which was widely used for the material test.
- (2) However, the reduction factor decreased and the strength of the welded joint specimen approached the base metal data with the increase of the gage length.
- (3) It is expected that a lower fatigue strength reduction factor can be applied for the weldment of LMFBR components, because the representative dimensions of actual structures are much larger than the size of inhomogeneous region adjacent to the weld line.

#### ACKNOWLEDGEMENT

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#### REFERENCES

Table 1 Chemical composition

Material	Chemical composition (wt%)									
	C	Si	Mn	P	S	Ni	Cr	Mo	N	Al
316FR	0.009	0.56	0.87	0.025	0.004	11.20	16.83	2.10	0.077	0.02
Weld metal	0.008	0.47	1.30	0.025	<0.005	11.4	18.6	2.04	0.080	0.010

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2. Corum, J. M., 1990, J. of Pressure Vessel Technology, Trans. of the ASME, Vol.112: pp.333-339.
3. Koto, H., Sakon, T. and Kaguchi, H., 1991, The 1st JSME/ASME Joint Int. Conf. on Nuclear Engin., C-19: pp.637-641.

Table 2 Test conditions

Specimen name	Temperature T (°C)	Strain range $\Delta \epsilon$ (%)	Hold time $t_H$ (h)	Specimen type	
2MJ1	550	1.0	0	A	
2MJ2				B	
2MJ4				C	
3MJ9			1	C	
3MJ1			0.5	0	A
3MJ5					B
3MJ7	C				

Specimen type	t (mm)	W (mm)	Gage length of extensometer (mm)			
			Strain control E0	Local strain measurement		
			E1	E2	E3	
A	10	20	15	—	2	—
B	20	40	35	15	2	2
C	40	40	50	15	2	2

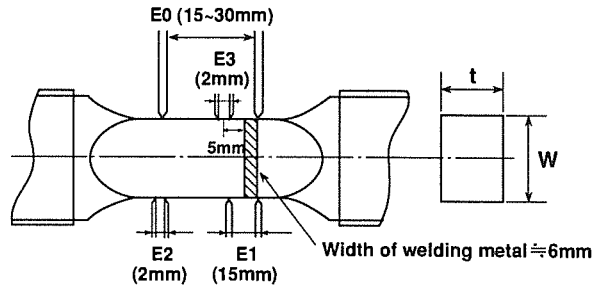
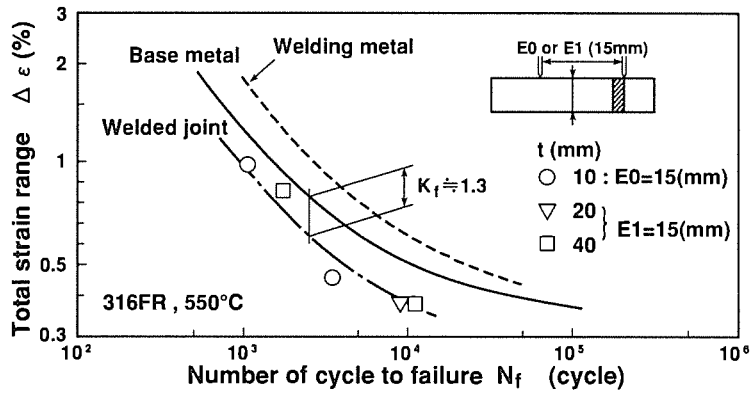
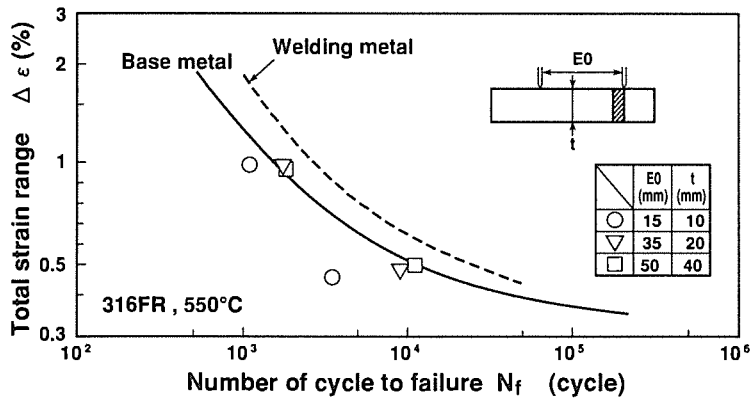


Fig.1 Specimen dimensions and summary of extensometer's locations



(a) Thickness effect



(b) Gage length effect

Fig.2 Thickness and gage length effect on fatigue strength of 316FR welded joint specimen

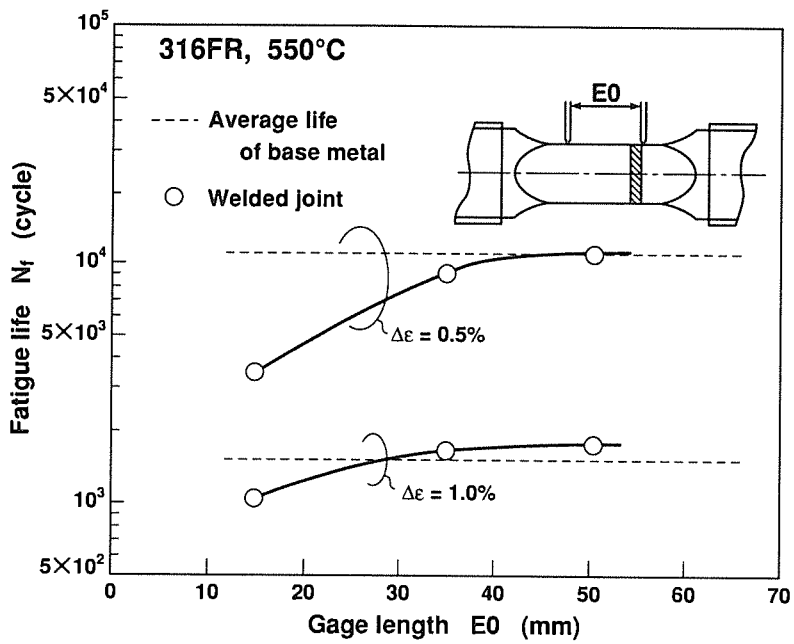


Fig.3 Fatigue life vs. gage length of welded joint

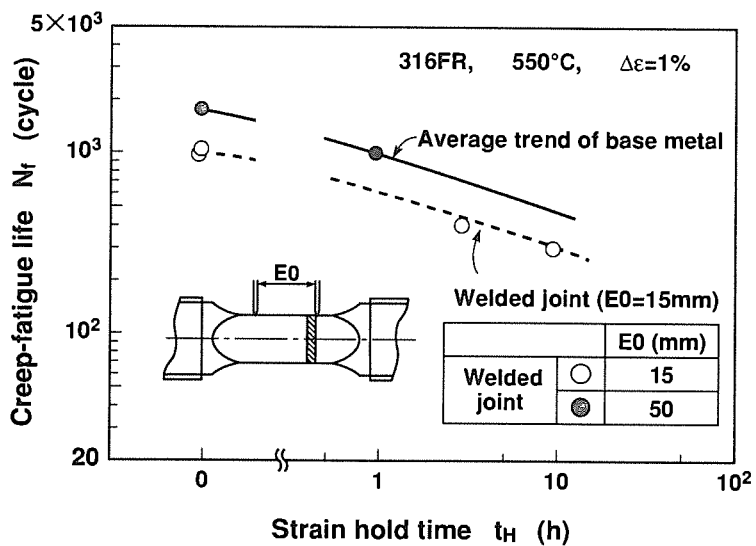


Fig.4 Gage length effect on the creep-fatigue life of welded joint

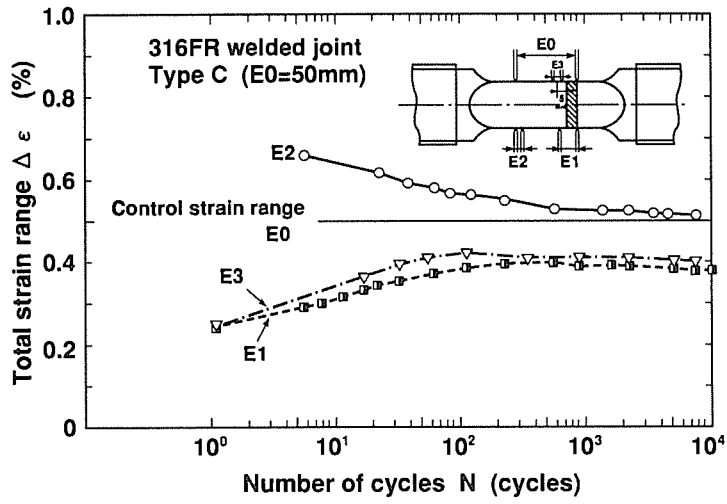
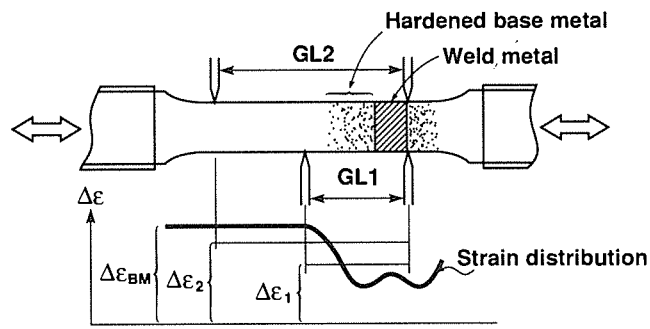
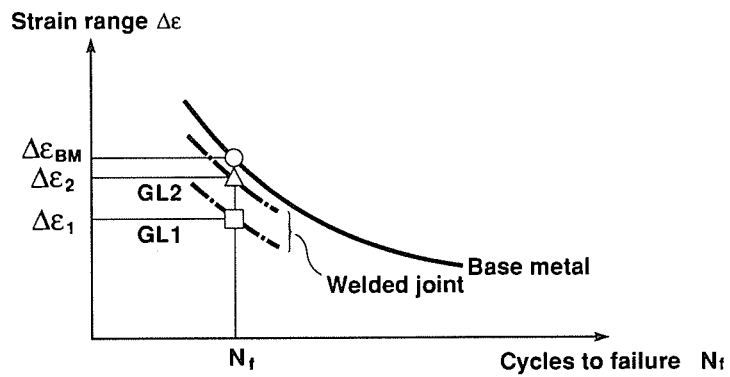


Fig.5 Example of measured local strain behavior of welded joint



(a) Strain distribution in the welded joint specimen



(b) Fatigue strength of welded joint

Fig.6 Schema of strain distribution and gage length effect on fatigue strength of welded joint