FATIGUE STRENGTH OF CP GRADE 2 TITANIUM FILLET WELDED JOINT FOR SHIP STRUCTURE

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ABSTRACT

Titanium is suitable for the material of ship hull structures because of its high specific strength responding to high-speed demanding and high corrosion resistance in marine environment. In Japan, CP titanium plates have been already used for the structural members of fishing boats. However, there is no application of the structural members of merchant or government ships where the authorized standard is strict, because there is no suitable rule or recommendation for welded built-up titanium plate structures. Additionally, there is little research concerned with the fatigue strength of titanium fillet welded joints that are indispensable to ship structure. In this study, for promoting the development of titanium ships, the fatigue tests of butt-welded joints, transverse fillet welded joints and longitudinal fillet welded joints were carried out. As a result of mentioned above, the effectiveness of the fatigue strength of steel was investigated for designing on the safety judgment of titanium-welded joints. Good correlation was achieved between the fatigue test results obtained from three types of welded joint relevant to ships that fail from the weld toe, using a modified version of the equivalent stress defined in MIL-HDBK-5. Furthermore, similar results were obtained for base metal failure.

IIW-Thesaurus keywords: *GTA welding; Arc welding; Gas shielded arc welding; Titanium; Shipbuilding; Fatigue strength; Mechanical properties; Fatigue tests; Mechanical tests; Welded joints; Stress distribution; Residual stresses; Measurement; Crack initiation; Weld toes; Parent material; Practical investigations; Thickness; Dimensions; Size; Comparisons; Steels; GMA welding.*

1 INTRODUCTION

1.1 Background of this study

Commercial pure titanium has already been used for seawater cooling pipe on thermal power plant because of its high corrosion resistance in seawater. Additionally, the advantage of its high specific strength has already been proved on racing yacht. However, there are no other ships, except a few fishing boats whose hulls are made from titanium. The main problem in using commercial pure titanium for structural members is the lack of strength data for base metals and welded joints. On the other hand, application of titanium is expanding to auxiliary and rigging members such as rudders, shaft blankets and laying pipes for seawater cooling. It seems that there is no limitation to the application of titanium for upper structural members. Titanium is especially profitable in case of laying pipes, considering the cost of maintenance during the long life cycle and recycling.

1.2 Object of this study

The object of this study was to evaluate the fatigue strength of welded joints relevant to the use of thin commercial pure titanium plate for laying pipes and upper deck structure in ships. As will be seen, the study provided fatigue test results for base metal, butt-welded joints, transverse fillet welded joints and longitudinal fillet welded joints in 2 and 10 mm thick JIS Grade 2 commercial pure titanium plate. The results were then assessed as a basis for the application of titanium using a modified version of the approach contained in the US Military Standard usually applied to aircraft MIL-HDBK-5 [1,2].

2 TEST METHOD

2.1 Test material

The test specimens were manufactured using 2 and 10 mm thick commercial pure titanium mill products (JIS H4600 TP340C/H). The mechanical properties are shown in Table 1. It will be observed that the 0.2% proof strength transverse to the rolling direction is higher than that in rolling direction.

2.2 Test specimen

The test specimens are shown in Figure 1. These were made with their lengths both along and transverse to the plate rolling direction, referred to as L or C respectively. Furthermore, the butt-welded joints, transverse fillet welded joints or longitudinal fillet welded joints are

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Table 1. Mechanical properties.

Orientation with respect to rolling direction	Thickness (mm)	0.2% Proof strength (MPa)	Tensile strength (MPa)	Elongation %
Along	2	223	365	61
Transverse	2	288	349	79
Along	10	319	489	60
Transverse	10	406	507	47

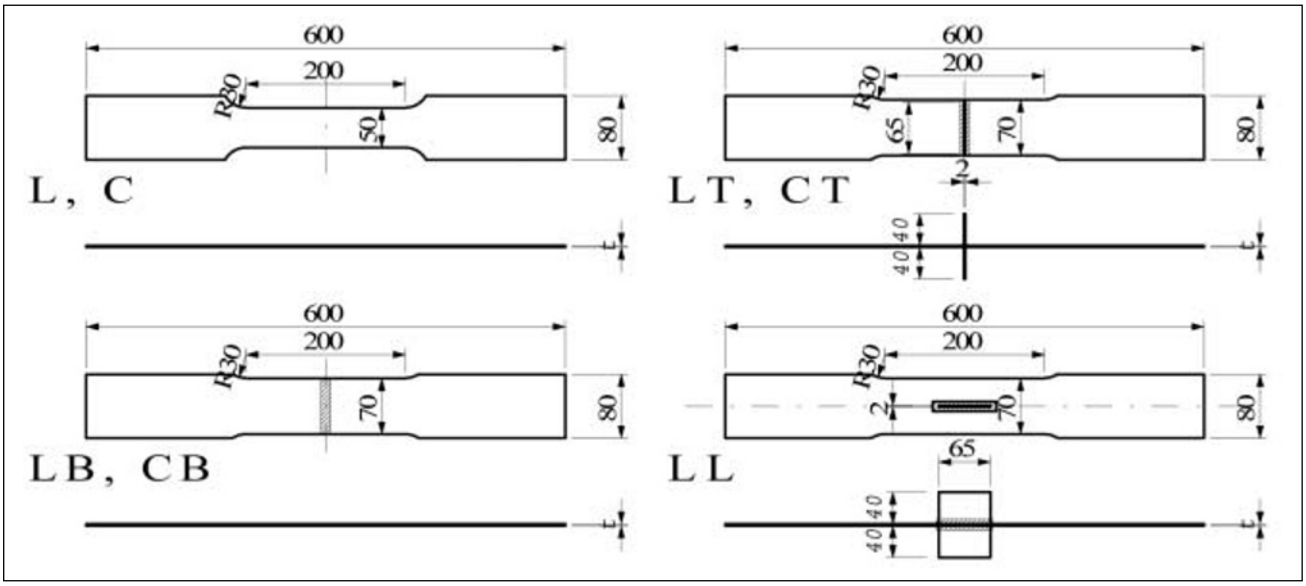


Fig. 1. Test specimens.

referred to as B, T or L respectively. The welded joints were fabricated by manual TIG welding; therefore there was some variation in welding conditions. 1.6 or 2.4 mm diameter JIS Z3331 YTB35 welding rod was used. Argon was used for welding and back shielding gas. The welding conditions are shown in Table 2.

2.3 Test method

Tensile and fatigue tests were carried out on all seven-types of test specimen (L, C, LB, CB, LT, CT and LL). The five-types of welded specimen (LB, CB, LT, CT and LL) were instrumented with strain gauges to determine the stress distribution approaching the weld in the tensile tests. The results were used to estimate the stress concentration due to the weld detail. In addition, residual stress measurement were carried out on the same five-types of welded specimens. This was done using the conventional strain release method by cutting strain gauged specimens. In the fatigue tests, the applied stress ratio was $R = 0$ and the cycling frequency was 5 Hz.

3 TEST RESULTS AND DISCUSSION

3.1 Stress concentration measurement

In this paper, the stress concentration due to the welded joint is separated into two categories. One is that caused by the local configuration of welded section. The other is that caused by the arrangement of the structural members. Fatigue evaluation including allowance for this structural stress concentration is usually called the Hot-spot stress method. In this method, the butt-welded and transverse fillet welded joints are considered as the basic joints, for which the structural stress concentration factor K_t is set to 1.0. The structural stress concentration

Table 2. Welding conditions.

Joint type	Current (A)		Voltage (V)		Welding speed (cm/min)		Heat input (MJ/m)	
	2 mm	10 mm	2 mm	10 mm	2 mm	10 mm	2 mm	10 mm
LB	90,0	220	17,5	13,0	12,6	19,4	747	885
CB	84,5	220	16,4	13,0	12,4	18,0	669	953
LT	73,2	180	13,4	11,0	13,5	17,0	436	699
CT	73,6	180	13,6	11,0	13,1	17,2	456	689
LL	73,5	180	13,7	11,0	10,0	17,0	604	699

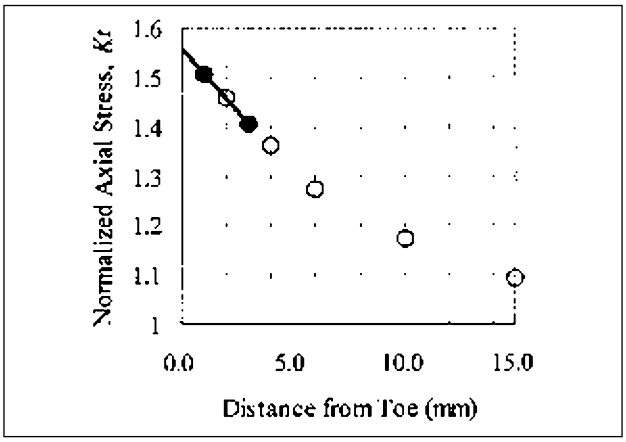
factor for the longitudinal fillet welded joint is then the ratio of the structural stress in this joint to that in the basic joint. Though there are many methods to determine the structural hot-spot stress, that recommended in SR202B [3] was used in this paper.

The stress distribution on the central axis of the longitudinal fillet welded specimen under tensile loading is shown in Figure 2. The horizontal axis shows the distance from weld toe and the vertical axis shows the axial stress normalized by the nominal stress.

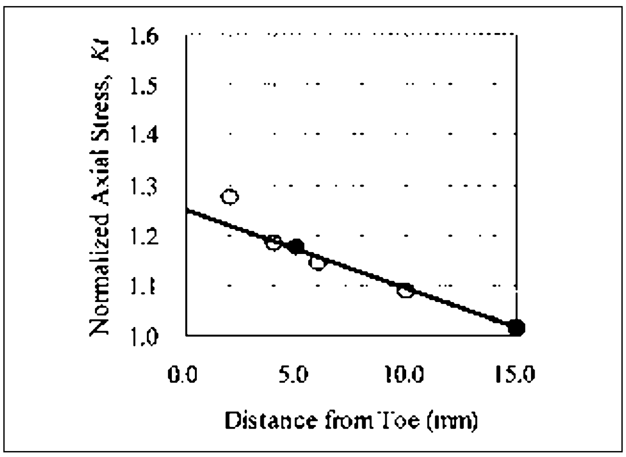
The stress concentration factor corresponding to the standard of Hot-spot stress based on the SR202B method is calculated by linear-extrapolation to the weld toe section using the stress values at two points, 0.5 and 1.5 times the plate thickness from the welded toe. Thus, from the stress values on the fitted curves at 1.0 and 3.0 mm (2 mm thickness) or 5.0 and 15.0 mm (10 mm thickness), K_t is found to be 1.56 in the 2 mm thick specimen or 1.25 in the 10 mm. The extrapolation lines are shown in Figure 2.

3.2 Residual stress measurement

The results of the residual stress measurement are shown in Figure 3. The average residual stress in the butt-welded joint was either 37.5 MPa (2 mm thick) or

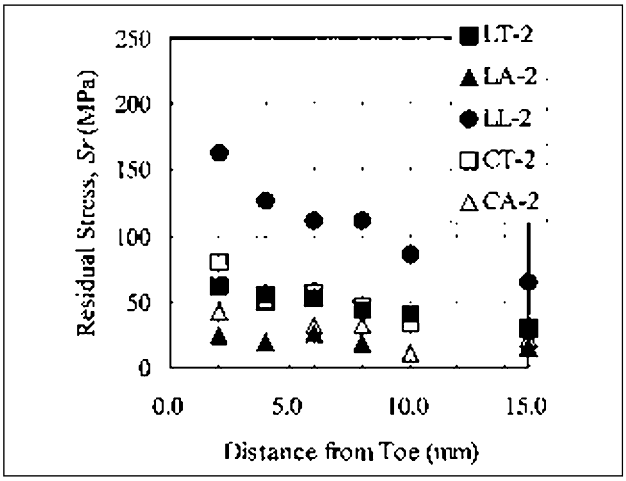


(a) 2 mm thickness

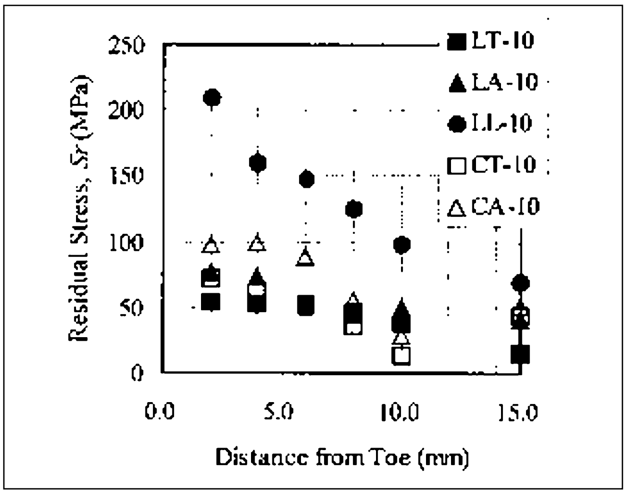


(b) 10 mm thickness

Fig. 2. Axial stress distribution in a longitudinal fillet welded specimen (LL).



(a) 2 mm thickness



(b) 10 mm thickness

Fig. 3. Residual stress distribution in the five types of welded joint.

92.9 MPa (10 mm thick). That in the transverse fillet welded joint was either 70.9 MPa (2 mm) or 66.8 MPa (10 mm). Finally, that in the longitudinal fillet welded joint was either 181 MPa (2 mm) or 240 MPa (10 mm).

3.3 Fatigue test results

3.3.1 Analysis method

The US military handbook for aircraft materials (MIL-HDBK-5) [1], expresses the *S-N* relation in terms of an equivalent stress S_{eq} (equation (1)). This results in the relation between life *N* and S_{eq} given in equation (2).[1]

$$S_{eq} = S_{\max} (1 - R)^m \tag{1}$$

$$\log S_{eq} = \alpha + \beta \log N \tag{2}$$

Here, S_{max} is the maximum applied stress, $R = S_{min}/S_{max}$ is the stress ratio and *m* is the exponent to optimize S_{eq}–*N* relation.

[1] The *S – N* curve of the IIW Recommendation doc XIII-1539-96/XV-845-96: $\Delta S^n N = C$ can be determined from equation (2) parameters as follows: $n = -1/\beta$ and $\log(C) = -\alpha/\beta - \{(1-m)/\beta\} \log(1-R)$.

MIL-HDBK-5 refers specifically to aircraft materials and therefore it does not cover welded joints. On a welded structure, for example a ship, the fatigue damage initiates at welded joints. It is influenced by both the stress concentration and residual stress due to the welds. Therefore, the fatigue analysis method given in MIL-HDBK-5 [1] was modified to allow it to be used to evaluate the present results. This involved establishing an equivalent stress that allowed for the effect of both stress concentration and residual stress [2]. In this method, equation (1) is rewritten to give equation (3). Moreover, stress concentration and residual stress are considered by S_{max} and $S = S_{max} - S_{min}$ using equations (4) and (5).

$$
\begin{aligned}
S_{eq} &= S_{max}(1 - R)^m \\
&= S_{max}(S_{max}/S_{max} - S_{min}/S_{max})^m \\
&= S_{max}^{1-m}(S_{max} - S_{min})^m \\
&= S_{max}^{1-m} S_m \qquad (3)
\end{aligned}
$$

$$S_{max} = K_t S_{n,max} + S_r \qquad (4)$$

$$S = K_t (S_{n,max} - S_{n,min}) \qquad (5)$$

Here, $S_{n,max}$ is the maximum nominal (applied) stress and $S_{n,min}$ is the minimum nominal (applied) stress. On the other hand, S_{max} and S_{min} are the local stresses. Moreover, K_t is the structural stress concentration and S_r is the residual stress in the hot-spot region because the Hot-spot stress method is used in this paper.

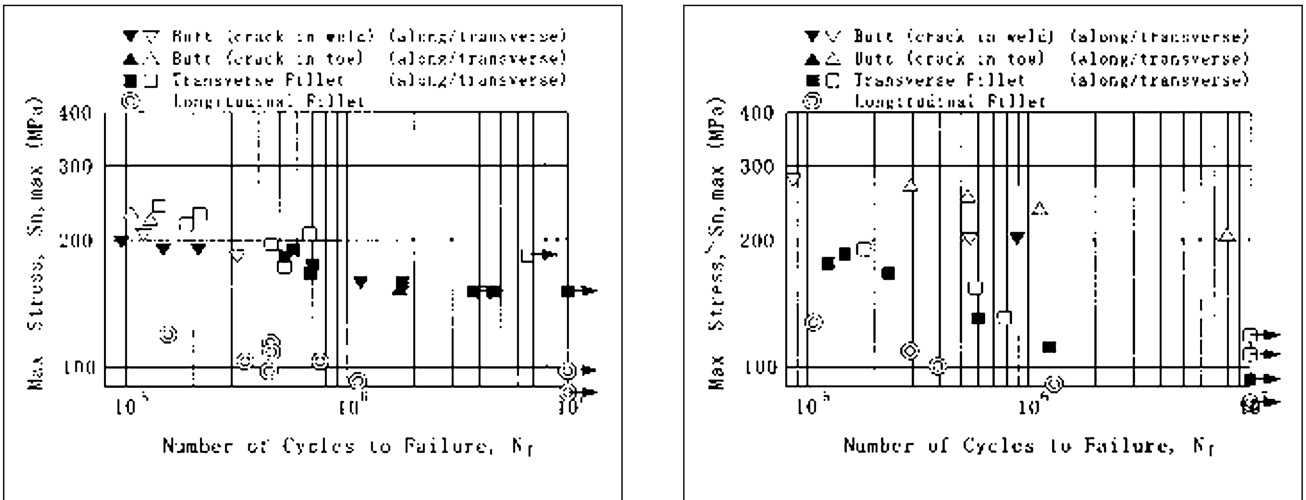
In the case of steel welded joints, it is normally assumed that yield magnitude residual stresses are induced with the result that S_{max} has the upper limit of yield strength [2]. However, the upper limit of S_{max} cannot be set in the case of aluminium alloy because it has no clear upper and lower yield point [4]. Similarly, commercial pure titanium has no clear yield point. Therefore, no upper limit of S_{max} based on equation (4) is set according to reference [4].

3.3.2 Crack initiation from the weld toe

The results for the test specimens in which the fatigue crack initiated at the weld toe or in the weld are shown in Figure 4. However, some of the specimens failed in the parent material rather than from the weld toe or weld and they are excluded. All the test results are shown in Tables 4 and 5.

Table 4. Fatigue test results in 2 mm thick specimens.

Specimen number	Maximum applied stress $S_{n,max}$ (MPa)	Number of cycles to failure	Crack initiation point
L-1	Reserve		
L-2	234.15	265 213	Base Metal
L-3	189.55	2 633 711	Base Metal
L-4	211.85	7 228 036	Base Metal
L-5	178.4	8 460 400	Base Metal
L-6	223	231 740	Base Metal
L-7	Tensile test		
L-8	200.7	499 850	Base Metal
L-9	156.1	10 000 000	Run Out
L-10	211.85	166 785	Base Metal
L-11	223	604 796	Base Metal
L-12	182.234	4 299 362	Base Metal
L-13	Tensile test		
LB-1	168	1 240 146	Base Metal
LB-2	Residual stress measurement		
LB-3	160	4 044 990	Continue
LB-4	160	Not yet tested	
LB-5	176	1 213 610	Base Metal
LB-6	160	1 153 690	Weld
LB-7	Tensile test		
LB-8	Tensile test		
LB-9	Reserve		
LB-10	192	147 130	Weld
LB-11	184	704 579	Base Metal
LB-12	200	95 956	Weld
LB-13	192	213 337	Weld
LB-14	152	1 734 430	Weld Toe
LT-1	Residual stress measurement		
LT-2	166.95	675 006	Weld Toe
LT-3	151.05	3 758 990	Continue
LT-4	151.05	10 000 000	Run Out
LT-5	190.8	568 020	Weld Toe



(a) 2 mm thickness

(b) 10 mm thickness

Fig. 4. Fatigue test results obtained from welded specimens.

Table 4 (continued)

Specimen number	Maximum applied stress $S_{n,max}$ (MPa)	Number of cycles to failure	Crack initiation point
LT-6	159	1 779 160	Weld Toe
LT-7	Tensile test		
LT-8	Tensile test		
LT-9	174.9	700 610	Weld Toe
LT-10	151.05	4 607 380	Weld Toe
LT-11	182.85	520 647	Weld Toe
LT-12	198.75	247 922	Base Metal
LT-13	Reserve		
C-1	Reserve		
C-2	273.6	181 319	Base Metal
C-3	244.8	1 210 226	Base Metal
C-4	244.8	619 843	Base Metal
C-5	230.4	10 000 000	Run Out
C-6	288	78 020	Base Metal
C-7	Tensile test		
C-8	259.2	189 000	Base Metal
C-9	252	244 980	Base Metal
C-10	216	2 874 252	Base Metal
C-11	240.768	943 355	Base Metal
C-12	237.6	380 300	Base Metal
C-13	Tensile test		
CB-1	221.4	2 640 835	Base Metal
CB-2	209.1	535 666	Base Metal
CB-3	172.2	9 259 210	Continue
CB-4	221.4	129 860	Weld Toe
CB-5	230	105 510	Weld Toe
CB-6	Tensile test		
CB-7	196.8	7 746 671	Continue
CB-8	Reserve		
CB-9	Tensile test		
CB-10	209.1	120 002	Weld
CB-11	184.5	318 616	Weld
CB-12	Residual stress measurement		
CB-13	196.8	3 191 404	Continue
CB-14	184.5	10 000 000	Run Out
CT-1	Reserve		
CT-2	149.5	4 213 944	Weld Toe
CT-3	218.5	188 779	Weld Toe
CT-4	241.5	142 287	Weld Toe
CT-5	184	6 609 800	Continue
CT-6	230	217 480	Weld Toe
CT-7	Tensile test		
CT-8	Tensile test		
CT-9	207	678 560	Weld Toe
CT-10	184	5 837 100	Base Metal
CT-11	172.5	520 930	Weld Toe
CT-12	195.5	451 247	Weld Toe
CT-13	Residual stress measurement		
LL-1	Residual stress measurement		
LL-2	87.2	10 000 000	Run Out
LL-3	114.45	447 552	Weld Toe
LL-4	103.55	346 169	Weld Toe
LL-5	103.55	752 370	Weld Toe
LL-6	109	453 840	Weld Toe
LL-7	Tensile test		
LL-8	Tensile test		
LL-9	119.9	155 380	Weld Toe
LL-10	98.1	10 000 000	Run Out
LL-11	98.1	441 284	Weld Toe
LL-12	92.65	1 116 913	Weld Toe
LL-13	Reserve		

Table 5. Fatigue test results in 10 mm thick specimens.

Specimen number	Maximum applied stress $S_{n,max}$ (MPa)	Number of cycles to failure	Crack initiation point
L-1	Tensile Test		
L-2	Tensile Test		
L-3	287	47 870	Base Metal
L-4	255	468 070	Base Metal
L-5	239	1 062 560	Base Metal
L-6	231	1 174 710	Base Metal
L-7	271	153 021	Base Metal
L-8	223	1 604 601	Base Metal
L-9	215	6 457 840	Base Metal
L-10	208	6 618 630	Base Metal
L-11	Reserve		
LB-1	Tensile test		
LB-2	183	893 460	Base Metal
LB-3	176	10 000 000	Run Out
LB-4	204	889 680	Weld
LB-5	217	552 240	Base Metal
LB-6	Residual stress measurement		
LB-7	Tensile test		
LB-8	231	201 823	Base Metal
LB-9	190	1 384 232	Base Metal
LB-10	190	1 432 725	Base Metal
LB-11	183	2 545 390	Base Metal
LB-12	Reserve		
LT-1	Tensile test		
LT-2	102	2 233 310	Weld Toe
LT-3	112	1 245 110	Weld Toe
LT-4	93	10 000 000	Run Out
LT-5	167	234 200	Weld Toe
LT-6	186	148 060	Weld Toe
LT-7	Residual stress measurement		
LT-8	177	123 150	Weld Toe
LT-9	130	597 260	Weld Toe
LT-10	Reserve		
LT-11	Tensile test		
C-1	Tensile test		
C-2	Tensile test		
C-3	324	123 160	Base Metal
C-4	284	2 937 590	Base Metal
C-5	304	269 610	Base Metal
C-6	294	666 000	Base Metal
C-7	289	757 190	Base Metal
C-8	274	369 550	Base Metal
C-9	264	7 714 430	Base Metal
C-10	Reserve		
CB-1	Tensile test		
CB-2	Instrumentation failure		
CB-3	280	86 350	Weld
CB-4	204	7 946 640	Weld Toe
CB-5	204	545 340	Weld
CB-6	Residual stress measurement		
CB-7	Tensile test		
CB-8	235	1 129 840	Weld Toe
CB-9	220	2 721 530	Base Metal
CB-10	267	292 640	Weld Toe
CB-11	251	534 280	Weld Toe
CB-12	Reserve		

Table 5 (continued)

Specimen number	Maximum applied stress $S_{n,max}$ (MPa)	Number of cycles to failure	Crack initiation point
CT-1	Tensile test		
CT-2	143	833 690	Weld Toe
CT-3	190	179 550	Weld Toe
CT-4	155	579 440	Weld Toe
CT-5	131	780 850	Weld Toe
CT-6	107	10 000 000	Run Out
CT-7	Residual stress measurement		
CT-8	119	10 000 000	Run Out
CT-9	131	Not yet tested	
CT-10	Reserve		
CT-11	Tensile test		
LL-1	Tensile test		
LL-2	87	833 690	Weld Toe
LL-3	100	390 630	Weld Toe
LL-4	109	291 890	Weld Toe
LL-5	128	106 080	Weld Toe
LL-6	164	39 740	Weld Toe
LL-7	Residual stress measurement		
LL-8	91	1 307 520	Weld Toe
LL-9	82	10 000 000	Run Out
LL-10	Reserve		
LL-11	Tensile test		

According to 3.1 and 3.2 mentioned above, the structural stress concentration for the butt and transverse fillet welded joint, K_t, was set to 1.0, the residual stresses in the butt-welded joints, S_r, were 37.5 MPa (2 mm) or 92.9 MPa (10 mm), while those in the transverse fillet welded joints were 70.9 MPa (2 mm) or 66.8 MPa (10 mm). In the case of the longitudinal fillet welded joints, K_t was 1.56 (2 mm) or 1.25 (10 mm) and S_r was 181 MPa (2 mm), 240 MPa (10 mm). These values were used to analyse the results obtained from the test specimens in which the crack initiated from the weld toe. S_{max} and S were calculated by equations (4) and (5). The coefficients m, α and β were determined by the least-squares method. The results are as following.

m = 0.673 (2 mm), 0.0550 (10 mm, B and L), 0.00 (10 mm, T) (6)

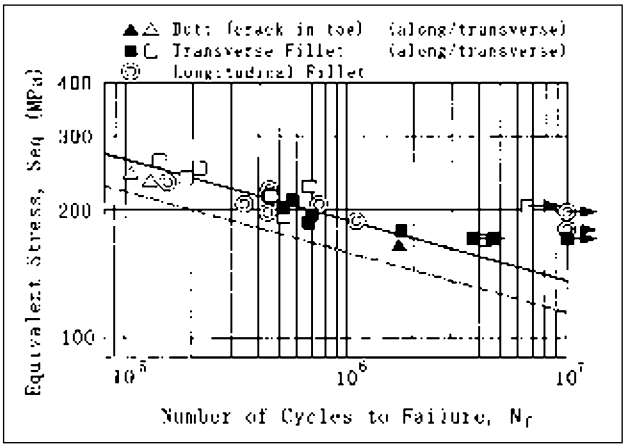
a = 3.14 (2 mm), 2.95 (10 mm, B and L), 3.21 (10 mm, T) (7)

b = – 0.143 (2 mm), – 0.0721 (10 mm, B and L) – 0.156 (10 mm, T) (8)

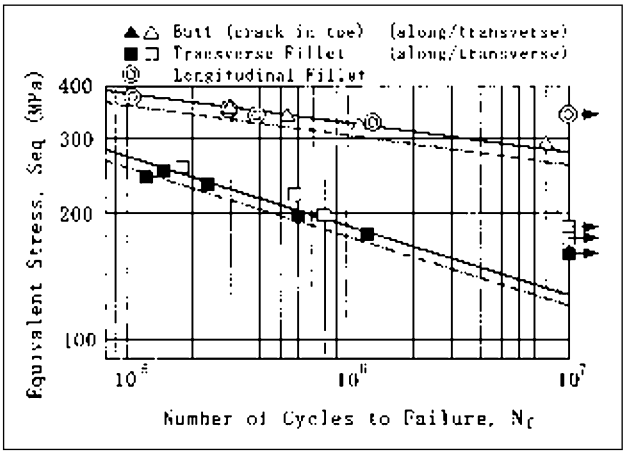
$\sigma(\alpha)$ = 0.0384 (2 mm), 0.0171 (10 mm, B and L), 0.0193 (10 mm, T) (9)

The parameter $\sigma(\alpha)$ of equation (9) is the standard deviation of the difference between log N obtained directly from test results and log N obtained from the S_{eq}–N relation, equation 2, and the test results calculated from equations (6), (7) and (8).

The fatigue test results in Figure 4 are presented in terms of S_{eq} in Figure 5. The solid lines are the 50% survival probability lines based on equation (2). The broken lines are the 97.5% survival probability lines calculated by subtracting two standard deviations of log N from the solid lines. Comparing Figure 4 and Figure 5,



(a) 2 mm thickness



(b) 10 mm thickness

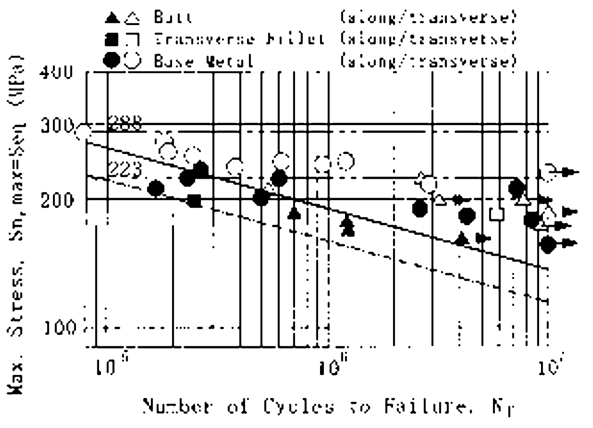
Fig. 5. Fatigue test results obtained from welded joints that failed from the weld toe expressed in terms of equivalent stress range S_{eq}.

it is clear that the modified MIL-HDBK-5 method has successfully correlated most of the test results from the various types of welded titanium specimen. However, in the case of 10 mm thick specimens, the results for the butt and longitudinal fillet-welded joints are not correlated with those of the transverse fillet-welded joints. The reason for this was not established in the present investigation. This is to be studied in future.

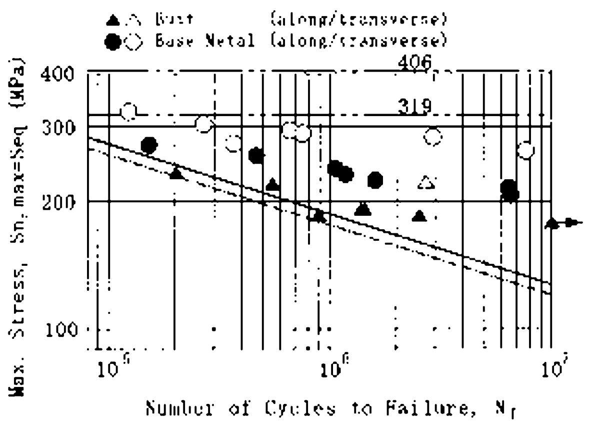
3.3.3 Crack initiation in the base metal

Since the base metal specimens were free from stress concentration and residual stress, the equivalent stress is equal to the applied stress range. Since in the present test R = 0, this is the same as the maximum applied stress. The same was assumed to apply to the weld specimens that failed in the base metal, since the crack locations were outside the influence of the stress concentration or residual stress effects of the welded joints.

The test results obtained from the base metal test specimens are shown in Figure 6. Also shown are the test results obtained from the welded specimens that failed in the base metal and the 50% (solid line) and 97.5% survival probability lines (broken line) obtained from the results obtained from welded specimens that failed from the weld toe. Finally, lines that indicate the 0.2% proof



(a) 2 mm thickness



(b) 10 mm thickness

Fig. 6. Fatigue test results obtained from specimens that failed in the base metal.

strength of the material (two point chain lines) are also shown. Comparing the results obtained from the base metal specimens, the fatigue strength is higher when the material is loaded transverse to the rolling direction. It seems that this is due to the difference in the proof strengths of the base metal. The same is evidently the case with the welded specimens that failed in the base metal.

All the test results that refer to crack initiation in the base metal section lie above the 97.5% survival probability lines corresponding to weld toe failure. Therefore, the S_{eq}–N relationships obtained from those results is suitable as the basis of a safety evaluation of the base metal itself.

3.3.4 Crack initiation in the weld

Figure 4 includes, the test results obtained from butt-welded joints that failed in the weld. As will be seen, the fatigue strength (nominal stress range or maximum applied stress) in this case is slightly lower than that of the specimens that failed from the weld toe. The reason for this was not established in the present investigation. It may have been due to the presence of higher, residual stress in the weld than that at the weld toe or the presence of weld defects (incomplete fusion and so on). This is to be studied in the future.

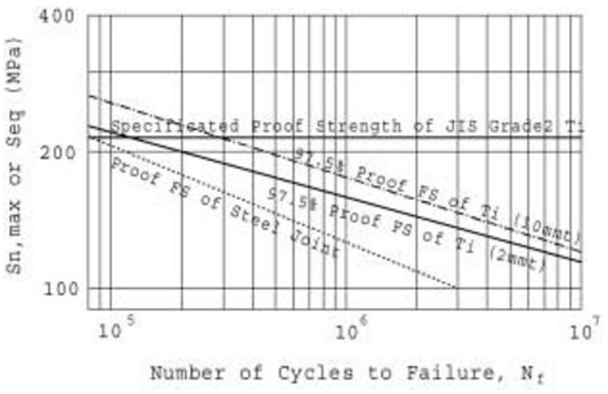


Fig. 7. Comparison between the fatigue strengths of titanium and steel welded joints.

3.4 Fatigue strength of CP grade 2 titanium welded joint

Fig. 7 shows a comparison between the fatigue strength of similar welded joint in steel and titanium, excluding the test results for weld failure in the latter. As in the case of the titanium results, the effects of residual stress and stress concentration in the steel specimens are included by using the equivalent stress based on equations (1) to (5). The difference is only that the upper limit of S_{max} is set to the yield strength in case of steel. In this figure, FS means fatigue strength. The solid line or the one point chain line shows the 97.5% survival probability lines (2 mm or 10 mm thickness respectively) for titanium. The dotted line shows the 97.5% survival probability line for steel. The specified 0.2% proof strength of JIS TP340 titanium, 215 MPa, is also shown.

For situations in which the nominal maximum stress is lower than the specified proof strength, the fatigue strengths of butt, transverse and longitudinal fillet-welded joints in commercial pure titanium are higher than those in steel. This was true in spite of structural stress concentration and large residual stress in the longitudinal fillet welded joints. This result was found using a modified version of the equivalent stress defined in MIL-HDBK-5, as shown in 3.3.1.

Therefore, it was found that it is not necessary to change the regulation or estimation of the fatigue strengths of welded ship structures in commercial pure titanium into one strictly comparable with those in steel.

It may be noted that the fatigue strengths of welded joints are generally in proportion to the elastic modulus of material. However, this is not the case with present results, since the modulus for titanium is around half that for steel but higher fatigue strengths were obtained in the long life regime. A possible reason is that the results presented here were obtained from welds made by different welding process. In particular, the dotted line in Figure 7 refers to results obtained from carbon dioxide MIG welded steel specimens, but the lines for titanium refer to results obtained from argon TIG welds. TIG welds have smoother, more favourable weld profiles than MIG welds, with the results that their fatigue performance can be better. Therefore, direct comparison of steel and titanium in Figure 7 may not be strictly valid and the figure should be viewed with caution.

4 CONCLUDING REMARKS

The fatigue strength of welded joints in JIS TP340 commercial pure titanium was investigated using 2 and 10 mm thickness mill product. The summarized results are as following.

1) Good correlation between the fatigue test results obtained from three types of principal welded joints in ship structures that fail from the welded toe was achieved using a modified version of the equivalent stress defined in MIL-HDBK-5.

2) Furthermore, similar results were obtained for base metal failure and therefore the above relations between equivalent stress and number of cycles to failure for welds are suitable for assessing potential base metal fatigue failure.

3) On the basis of the modified MIL-HDBK-5 equivalent stress, in the high-cycle regime the fatigue strengths of welded joints in commercial pure titanium were found to be higher than those in steel. However, this conclusion should be viewed with caution since the test specimens concerned were welded with different welding process, namely MIG for steel and TIG for the titanium.

4) However, good correlation was not achieved between the results for the butt and longitudinal fillet welded joints and those of transverse fillet welded joints in 1 mm material. The reason for this was not established in the present investigation but will be studied in future.

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