A FATIGUE ANALYSIS OF THE EFFECT OF LOCAL GEOMETRY IN TOE GROUND WELDED JOINTS

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In this paper numerical results of both the stress concentration factor K_t, and the stress magnifying factor M_{Ka}, at the weld toe obtained by FE modelling are presented for welded joints with the local geometry at the weld toe modified by toe grinding treatment. The results are presented and compared for two cases: a smooth contour at the weld toe with the main plate (plain weld) and a groove geometry of circular type at the same location. For both butt and cruciform joints, previously detected differences in fatigue behaviour, are explained by the results herein obtained for K_t and M_K. When grooves are produced, the values of K_t were found generally not to be below those of the equivalent plain toe ground joints. K_t and M_{Ka} data is given as a function of groove depth, h_u, and the radius of curvature R for the plain joints, and the radius of curvature, R_e, of the groove.

INTRODUCTION

Toe grinding is very frequently used as an improvement technique to increase the fatigue life of welded joints (1). If the method is properly applied it is possible to obtain increases in fatigue strength varying between 60 and 130% of the fatigue strength of the similar geometry without toe grinding (2,3). Weld toe grinding is only benefitial if there is an increase in the radius of curvature, R, and a decrease in the weld toe angle, γ, (Fig. 1a, b). If a groove is produced (Fig. 1c, d) the benefitial effect of the treatment could be reduced or eliminated. Results previously obtained by the authors (3) in fatigue tests at R=0 in both butt and cruciform joints of a C-M_n pressure vessel steel, have shown that in certain groove geometries the fatigue strength has even fallen below of the values for the as welded joints.

Hence, a detailed study was initiated to assess the influence of weld toe geometry in the fatigue strength of ground welds with the objectives of computing the appropriate values of both the stress concentration factor, K_t, and the stress magnifying factor, M_K, for the geometric parameters defined in Fig. 1.

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This paper presents the preliminary results obtained on toe ground welds with and without grooves (plain welds). These results will allow the optimization of the fatigue behaviour and will be used to define the limits of the acceptable toe ground geometries, so as to maximize the benefitial effects of the treatment.

METHODOLOGY

The values of K_t and M_K were obtained for the set of parameters in Table 1. For the plain welds the first series of numbers refers to the main plate. For the groove geometries the first number also indicates the main plate thickness, and the next two numbers refer, respectively, to the depth of the groove, hu, and the external weld toe radius, R_e (Fig. 1c), d)). R_i was kept constant= 2.5 mm. For the plain welds the values of R=1.9, 3.7 and 5.6 mm are the mean and extreme values of the toe radius obtained from a statistical analysis of 50 to 100 measurements. The R values of 8.0 and 5.0 refer to the circular contour of the chord for the thickness B, of 24 and 3 mm respectively. The values of R_e refered above are in agreement with published data (4,5).

For the groove geometries of 24 mm plate thickness the values of R_i and R_e were also obtained from local measurements. For the groove depths, h_u, the value of 0.8 mm is the mean experimental value obtained for 24 mm plate thickness. The value, h_u=0.5 mm, gives /y/B)=0.167 which is, for the 3 mm plate thickness, a non acceptable limit included in fatigue design codes (6,7). The remaining values of h_u (0.15 and 1.2 mm) correspond to 5% of the plate thickness (y/B=0.05) which is the recommended reduction in cross sectional areas induced by toe grinding (6,7).

The stress concentration factors, K_t, at the weld toe line, y/B, were obtained by a 2DFE package with eight node isoparametric elements. K_t was given as the ratio between the maximum stress, σ_x, and the nominal stress, σ_{non}, in the same location. M_K was computed as the ratio between the stress intensity factor K of a semi-eliptical crack of depth, a, and the reference stress intensity factor, K_r for a crack in a plate loaded in uniform tension without the weldment (8).

The values of K were obtained by weight functions (9) using a previous analysis developed by the authors (10). Both for the K_t and M_K formulations good numerical correlations were obtained with 5th or 6th order polynomial equations.

RESULTS

Table 1 gives the values of K_t which occurred at the plate surface for both types of joints. In the plain joints (Fig. 1a, b) the critical point was in the weld toe intersection while in the joints with grooves (Fig. 1c, d), in some cases, the critical point of maximum stress has changed to the mean section of the groove radius.

TABLE 1- K_t values for the joints in Fig. 1

PLAIN JOINTS (FIG. 1a, b)				
JK/24/1.0	JK/24/1.9*	JK/24/3.7	JK/24/5.6	JK/24/8.0
3.22	2.56	2.07	1.85	1.64
JT/24/1.0	JT/24/1.9	JT/24/3.7	JT/24/5.6	JT/24/8.0
2.39	2.03	1.77	1.57	1.46
JK/03/1.0	JK/03/1.9*	JK/03/3.7	JK/03/5.0	
1.62	1.39	1.21	1.16	
JT/03/1.0	JT/03/1.9*	JT/03/3.7	JT/03/5.0	
1.61	1.37	1.20	1.15	
JOINTS WITH GROOVES (FIG. 1c, d)				
K24/1.2/2.7	K24/1.2/11.8	K24/0.5/2.7	K24/0.5/11.8	
2.74	1.70	2.47	1.59	
T24/1.2/2.7	T24/1.2/11.8	T24/0.5/2.7	T24/0.5/11.8	
2.24	1.60	1.75	1.38	
K03/0.5/3.5	K03/0.5/1.5	K03/0.15/3.5	K03/0.15/1.5	
1.78	2.58	1.38	1.69	
T03/0.5/3.5	T03/0.5/1.5	T03/0.15/3.5	T03/0.15/1.5	
1.79	2.15	1.37	1.58	
K- Cruciform joints; T- Butt joints; * Not shown in the plots.				

The plots K_t against y/B, for the plain joints are in Fig. 2a) (butt welds) and 2b) (cruciform joints). K_t is higher in the K joints and increases with the main plate thickness. The reduction of K_t with the increase in the radius of curvature at the weld toe is also apparent specially for the 24mm plate thickness. For the 3 mm plate thickness, and for the higher R values, including the circular shape with R=5.0 mm, it is seen that very low values of K_t were obtained (below 1.25). For the 24 mm plate thickness, and for the smaller R value of 1.0 mm, the values of K_t are above 2.2 (curves 1 in Fig. 2a, b)). Only a significant stress gradient was obtained for the 24 mm plate thickness (curves 1 to 3, fig. 2a), b)).

The plots of M_{Ka} against a/B are in fig. 3a) for the butt joints and Fig. 3b) for the cruciform joints. Similar to K_t, M_{Ka} increases with the plate thickness and decreases when the values of R are increased. Only for the thickness of 24 mm (all cases) and 3 mm plate thickness with R=1 mm, the M_{Ka} gradient is steep. In the remaining cases the variation of M_{Ka} with a/B is small, for example, for the 3 mm plate thickness and radius of 3.7 and 5.0 mm the values of M_{Ka} are below 1.15 (Fig. 3a), b)). For the joints with grooves the K_t values (Table 1) are plotted in Fig. 4a), b)). For the eight geometries in Table 1, K_t values are higher in the cruciform joints against the butt joints. For the 3 mm plate thickness, the critical section, with the highest value, is the mean section of the groove (Fig. 1) (y/B= 0.167 and y/B=0.05; curves 5 to 8 in fig. 4a), b). For the 24 mm plate thickness the critical points lie very close to the weld toe with y/B<0.03 (curves 1 to 4 in Fig. 4). The stress gradient is higher than in the plain joints. The results (Table 1 and Fig. 4) show that the radius of curvature at the weld toe has a stronger influence on the values of K_t than the depth of the groove. However, for the thickness of 24 mm, and when the radius Re is high enough, above the maximum value tested (11.8 mm) little variation was obtained in the values of K_t when the depth of the groove was reduced. In order to take benefit of the groove geometry in terms of the reduction of K_t in comparison with the plain joints, the depth of the groove should be below 0.5 mm ($y/B<0.0208$) together with a external radius R_e above 11.8 mm (Table 1 and Figs. 2 and 4).

In the thin sections, (3 mm) for both groove depths of 0.5 and 0.15 mm there is a marked increase in the K_t values in comparison with the K_t values for the plain joints. Hence, there is no benefit in introducing this type of groove geometry even for the highest external radius, R_e=3.5 mm. This finding is in agreement with published data (11). For the 3 mm thin section the values of K_t obtained for the groove geometries were always above the equivalent plain geometries (Table 1).

M_{Ka} results for the weld toe groove geometry were also obtained and an increase of about 100% was found in the M_{Ka} values of the groove geometries.

CONCLUSIONS

In plain toe ground welds, both K_t and M_{Ka}, have increased with the decrease of the weld toe radius. In the groove welds, the stress concentration factor, K_t have increased with the reduction of the groove depth and increase of the external radius. The values of K_t are less dependent on the groove depth than the external radius of the groove.

For the weld toes with grooves, lower values of K_t than the equivalent ones obtained in plain weld toes, can only be obtained if the groove depth is below 5% of the main plate thickness and simultaneously the external radius of the groove is higher than 1.5 times the plate thickness. In these conditions an improvement in fatigue strength of the joint with groove will be expected in relation with the plain toe ground joints.

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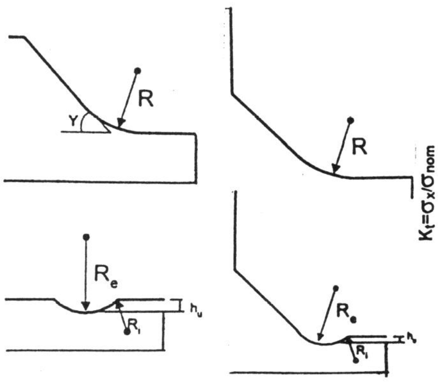
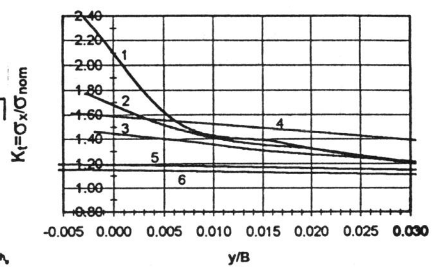
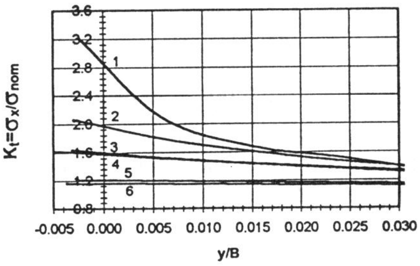
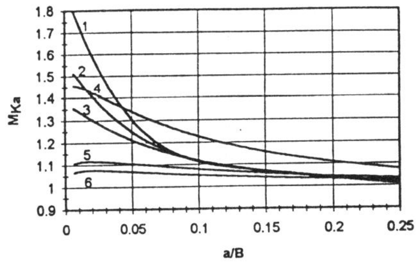


Fig. 1- Weld toe. a)Plain butt. b) Plain K. c) Butt with groove.d) K with groove



1-24/1.0;2-24/3.7;3-24/8.0; 4-03/1.0; 5-0.3/3.7; 6- 0.3/5.0.
Fig. 2a)- K_t vs. y/B. Plain butt welds.





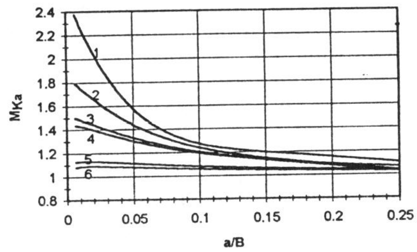
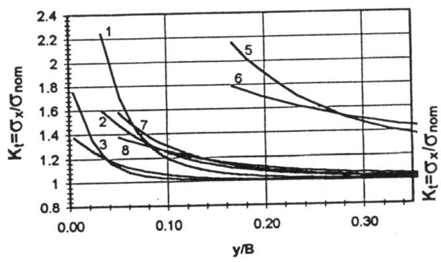
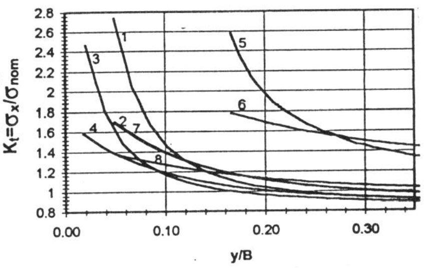


Fig. 2b) K_t vs. y/B. Plain K welds. Caption as Fig. 2 a)

Fig. 3a), b)-M_{Ka} vs a/B. Plain butt and K welds. Caption as Fig. 2a).





1-24/1.2/2.7; 2-24/1.2/11.8; 3-24/0.5/2.7; 4-24/0.5/11.8; 5-03/.05/1.5; 6-03/0.5/1.5; 7-03/0.15/1.5; 8-03/0.15/3.5

Fig. 4a)- Kt vs. y/B. Groove butt welds.

Fig. 4b)- Kt vs. y/B. Groove K welds.