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Fatigue Strength of Welded Butt Joints of Multiple Plate Flanges of Beams

Résistance à la fatigue d'assemblages en bout, des ailes de poutres constituées de tôles multiples

Ermüdungsfestigkeit der Stumpfnahtschweissverbindungen von Mehrblech-Trägergurten

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SUMMARY
The main cause of premature fracture of multiple-plate beam flanges is considered to be the concentration of stress at the point of intersection of the joint and the gap between the plates. A value of the effective concentration coefficient of B = 1.68 has been obtained for experimental specimens whereas, until now, B = 1 has been used. This new value of B should be considered as a lower bound for real structures because of possible assembly and welding defects.

RESUME
La rupture prématurée des ailes de poutres constituées de tôles multiples a pour principale cause la concentration de contraintes au point d'intersection de l'assemblage soudé et du vide entre les tôles. Une valeur du coefficient de concentration effectif B égale à 1.68 a été obtenue lors d'essais, alors que jusqu'à maintenant la valeur B = 1 a été utilisée. Cette nouvelle valeur de B doit être considérée comme une limite inférieure pour les structures réelles, en raison des imperfections possibles d'assemblage et de soudure.

ZUSAMMENFASSUNG
Die Hauptursache der vorzeitigen Ermüdungsbrüche der üblicherweise verwendeten geschweissten Stösse bei Mehrblech-Trägergurten ist die Spannungskonzentration im Kreuzungsbereich der Stossfuge mit dem Spielraum zwischen den Blechen. Aus Versuchen wurde ein Wert des Koeffizienten der effektiven Spannungskonzentration von B = 1.68 ermittelt, während bisher B = 1 angenommen worden war. Wegen der eventuellen Montage- und Schweissfehler ist der im Versuch ermittelte B-Wert als unterer Grenzwert für wirkliche Konstruktionen zu betrachten.

Conditions of superstructures erection determine the type of welded butt joints of multiple plate flanges of beams not typical for plant fabrication. Two weldment technologies are known: single-V (butt) joint with prefusion of gap between buut ends of welding edges [1-3] and separate joints by means of insersion pieces in pack plates [4] .

At our Institute attention has been paied for the first time to reliability of such joints during fatigue test of I-beams with double plate flanges. Beam flanges were welded with single - V (butt) joint according to the technology [1-3] . Tests were supposed to be conducted under variable load of 2 million cycles, however fatigue fracture of joints was found to initiate before specified time. In all cases fatigue crack occurred at the point of joint intersection with gap between plates (fig. 1).

The problem of fatigue strength of mentioned joints has not been sufficiently studied at the literature. In their investigations [2] the authors have made an attempt to define the cause of fracture. Irregularity of anglular contraction when performing single butt joint has been assumed to be the cause of fracture. As a result symmetrical grooves such as double V (butt) joint done by means of overhead welding have been recommended.

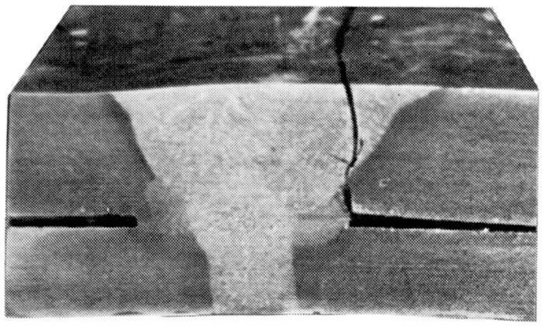

fig.1. Fatigue fracture of double plate beam flange joint

To estimate technologies applied we have conducted four series tests of double plate specimens on fatigue strength limit at variable tension (fig.2,a); series 1 - specimens of base metal; series 2 - specimens with single - V (butt) joints done according to the technology applied for one plate flanges; series 3 - specimens with single - V (butt joint) done according to the technology [1-3] ; series 4 - specimens with insertion in one of plates and three separate single - V (butt) joints done according to the technology [4]. In all specimens the gap between plates was welded along end block contours to provide coincidence of deformation of pack plates. After welding single - V (butt) joints were trimmed flush with base metal surface.

Series 1-3 were tested at two values of cycles asymmetry: $\rho = 0{,}125$ and $\rho = 0{,}40$; while series 4 - at $\rho = 0{,}40$. Crack being detected at one of the plates, tests were stopped. Obtained results were processed by the method of mathematical statistics. The fatigue strength curves were plotted in logarithmic coordinates (fig.2b,c).

Tests have demonstrated that regardless of the technology applied all specimens fracture (in beams as well - fig. 1) occurred at the point of joint intersection with gap between plates. Fatigue strength limit in series 2 and 4 (fig. 2,d) appeared to be the lowest and approximately the same at $\rho = 0{,}40$; fatigue strength limit in series 3 is slightly higher comparing with series 2 and 4, but lower in comparison with base metal (series 1). Tests conducted at $\rho = 0{,}125$ support the conclusions relative to series 2 and 3 (fig. 2c). The value of fatigue strength limit given in

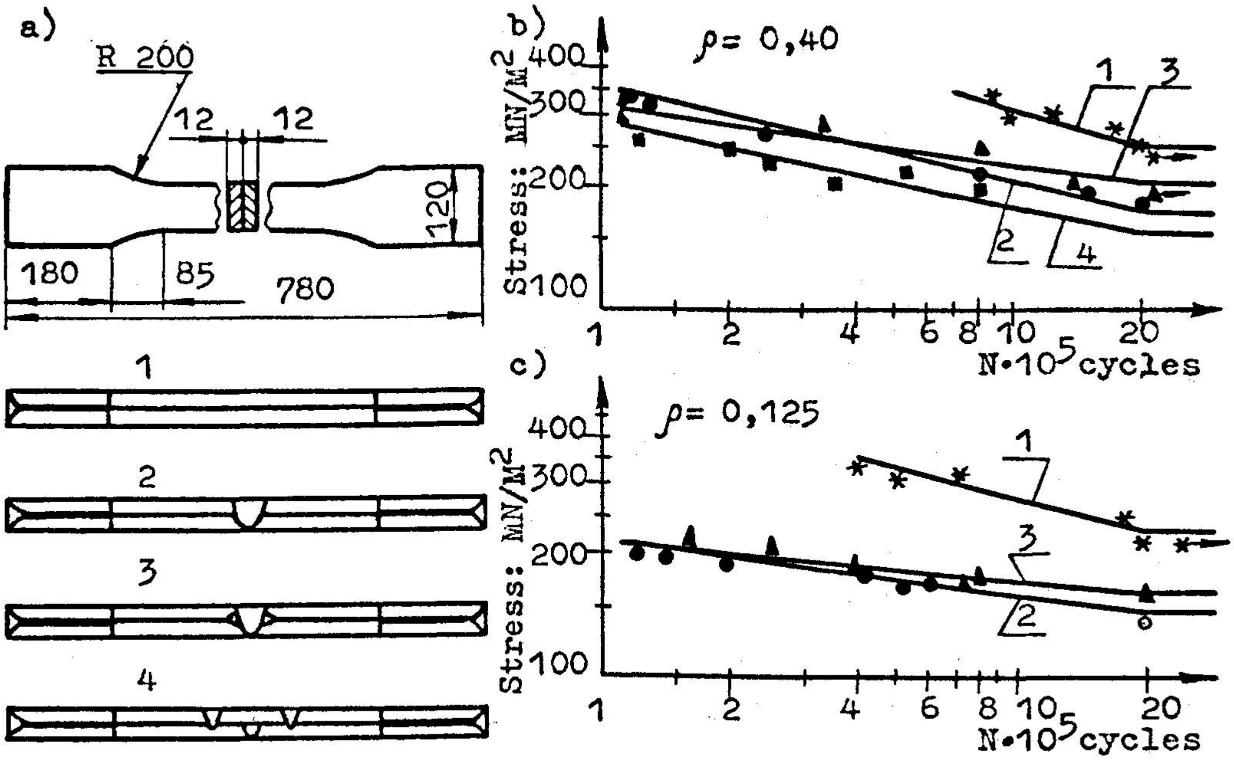

fig. 2. The curves of specimens fatigue strength (O – data from ref [2])

reference [2] for double V butt joint is shown here too. Fatigue strength limit of such joint obtained from "weak regime" tests ($\rho = 0,18$) appeared to be similar to fatigue strength limit at $\rho = 0,125$ in series 2. Therefore recommendations [2] haven't provided significant advantages.

Efficient coefficient of concentration was defined by means of maximum ultimate stress diagram by Smith [5] as ratio of base metal fatigue strength limit to joint fatigue strength limit at $\rho = -1$. For series 2 – B = 1,83, for series 3 – B = 1,68, the values being representative of quite high stress concentration in welded butt joints of multiple plate flanges, though up to the present it was considered to be absent and B = 1.

To find out the conditions of stress concentration occurrence the contours of points of joint intersection with gap between plates were investigated by means of microscope. It has been determined that in most cases the contours are close to rectangular (fig.3a). However in a number of cases distortions (defects) were observed such as spherical expansion with radius r at $\Delta < r << \delta_1, \delta_2$ (fig. 3b); sharp cross expansion of a specific size – 2a $\gg$ 2b, b $\cong \Delta < 2a << \delta_1, \delta_2$ and section form similar to elliptical (fig. 3c); branching from intersection point, section shape being close to elliptical with similar sizes ratio (fig. 3d). The mentioned defects have been induced by slag inclusions along the line of joint – gap intersection.

The methods of mathematical theory of elasticity have been used to estimate stress concentration in the above stated cases [6]. It was taken into account that thickness of pack plates and width of welded butt joint were much more than gap and defects sizes. This factor allowed the problem to be considered regardless of number and thickness of plates in a pack and mulual influence of gaps, and defects situated symmetrically relative to butt joint axis to be neglected.

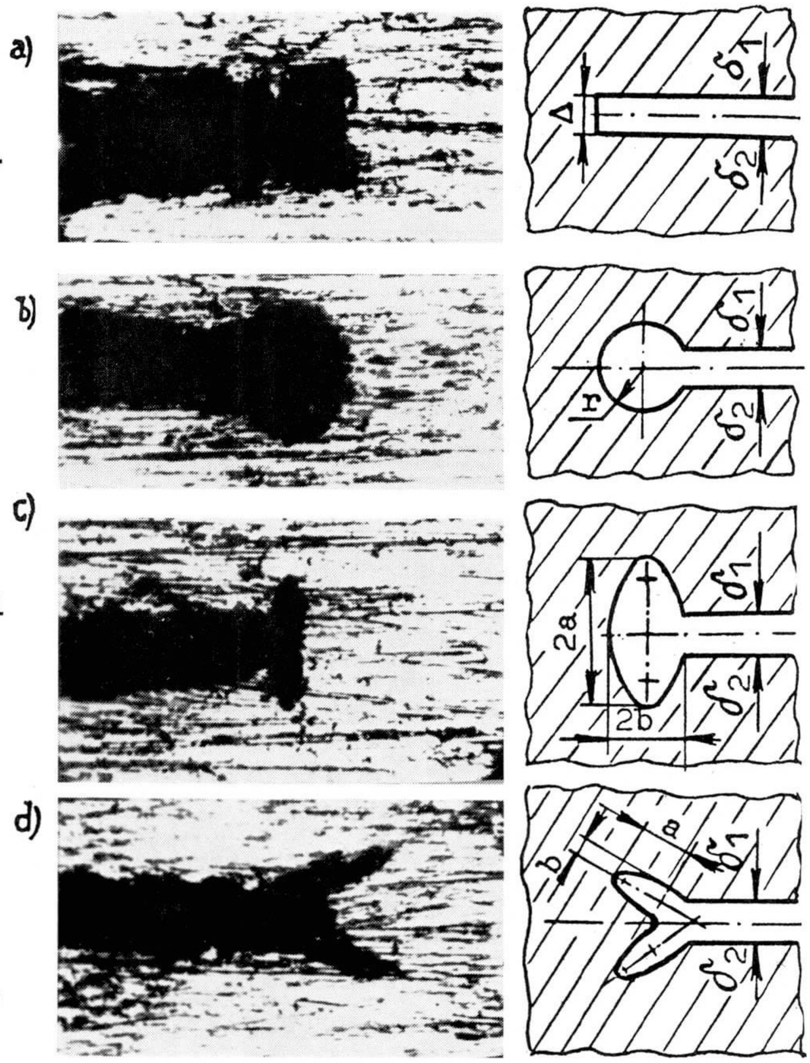

fig. 3. Zones of joint intersection with the gap

After geometrical approximation of points of joint intersection with gap (fig.3) it has been decided that mathematical problem of elasticity theory on extention of plane with various apertures is equivalent to the problem of elongation of welded butt joints of multiple plate packs.

Rectangular aperture of $a/\Delta = 2+2{,}5$ (sides ratio, fig 4a) was considered for fig.3a. In such aperture mutual influence of cross sides might be neglected within 3-4% [7]. It was found out that the value of theoretical coefficient of concentration K_t depends on radius r of aperture angle rounding off and is approximately identical for all long apertires, when ratio r/Δ is the same. In chart 1 it is obvions that value $K_t = 2{,}15$ even for the case when $r/\Delta = 0{,}5$. Such concentration coefficient will be evidently minimum for real connections. The results of analytical solution are qualitatively confirmed by investigations conduoded by photoelasticity method (chart 2). In practice there appears to be more cases when $r/\Delta < 0{,}5$. Charts 1 and 2 show that with r/Δ decrease the coefficient of concentration sharply increases.

The case of fig. 3 is interpolated as extention of plane with round aperture (fig. 4b) when $K_t = 3$ [6].

When plane with elliptical aperture extends the coefficient of concentration K_t depends on angle α, characterizing inclination of ellipse large axis to extention direction [6] Maximum meaning of K_t will be at the ends of large axis when $\alpha = \pi/2$ and corresponds to defects shown in fig. 3b. Such defects existing, coefficient of concentration [8] might be very high (fig. 4c). In all considered cases, where defects resulted from slag inclusions(fig.3,b,c,d), the gap should not affect concentration level as it is situated in the zone of least stresses.

Displacement of jointing pack plates is likely to take place when assembling butt joints and in the process of welding (fig. 5). In this case eccentricity of load occurs this being the cause of additional bending stress resulting in increase of total stress level. Thus displacement of 15% and 32% increases stress level by 1,34 and 1,84 [9]. Similar increase of total stress level occurs where there is residual angle deformations of connected plates [2]. Accordingly stress concentrators influence becomes larger.

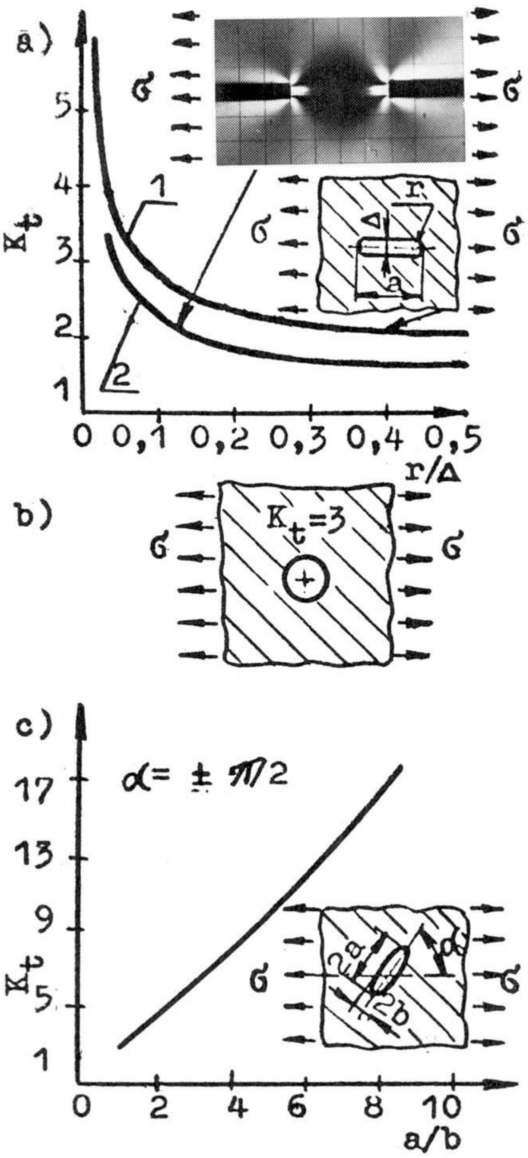

fig. 4. Theoretical concentration coefficients

Under construction conditions the occurrence of various assembling and welding defects is practically inevitable; that's why laboratory obtained value of efficient concentration coefficient B = 1,68 should be considered as lower meaning for real structures.

Higher fatigue strenght of series 3 (fig. 2) may be explained as follows. Joint circumjacent zone includes five sections of thermic influence zone (fig. 6). The sections hardness decreases as it is moved away from joint axis at HRB = 86 (in the first section) up to HRB = 68 (in the fifth section) These zones plasticity varies inversely with hardness. In series 2 concentrator is located in the zone of high hardness, but less elasticity (fig. 6a). In series 3 - in the zone of less hardness, but higher elasticity (fig. 6b). These factors determine the difference in connections behaviour under fatigue loading.

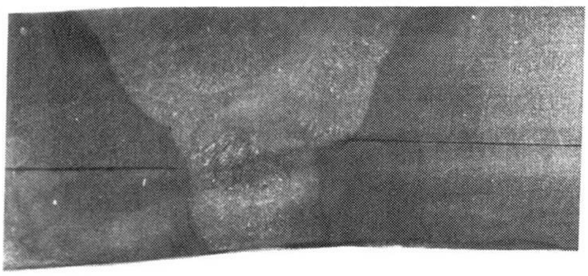

fig. 5. Fatigue fracture with displacement of plates in joint

In series 4 complete fusion (poor fusion is inadmissible in brid-

ge building results in fusion of butt joints metal with lower pack plate. Stress concentrators in connections of this series just as in series 2 are located in the zone of high hardness. As a result developed fatigue strength curves for this series appeared to be close one (fig. 2b) to another.
To determine the fracture mechanism of welded butt joint of multiple plate pack tests have been carried out on static tension of specimens possessing higher efficient coefficient of concentration B and specimens with artificial defects - apertures of 1,5 mm diameter simulating defect shown in fig. 3b. In both cases fracture initiated from the point of joint intersection with the gap (fig.7).

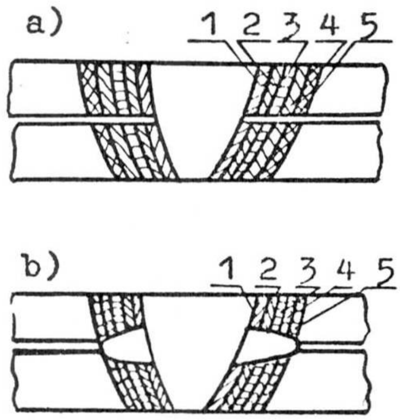

fig. 6. Concentrators location in joint circumjacent zone

Thus, in our opinion, high concentration of stress in the point of joint intersection with the gap between plates should be considered to be the main cause of fatigue fracture of welded butt joints of multiple plate beam flanges (packs). Such factors as hardness increase in joint circumjacent zone residual strains including angular, stresses and assembling and welding defects intensify the effect of the main cause.

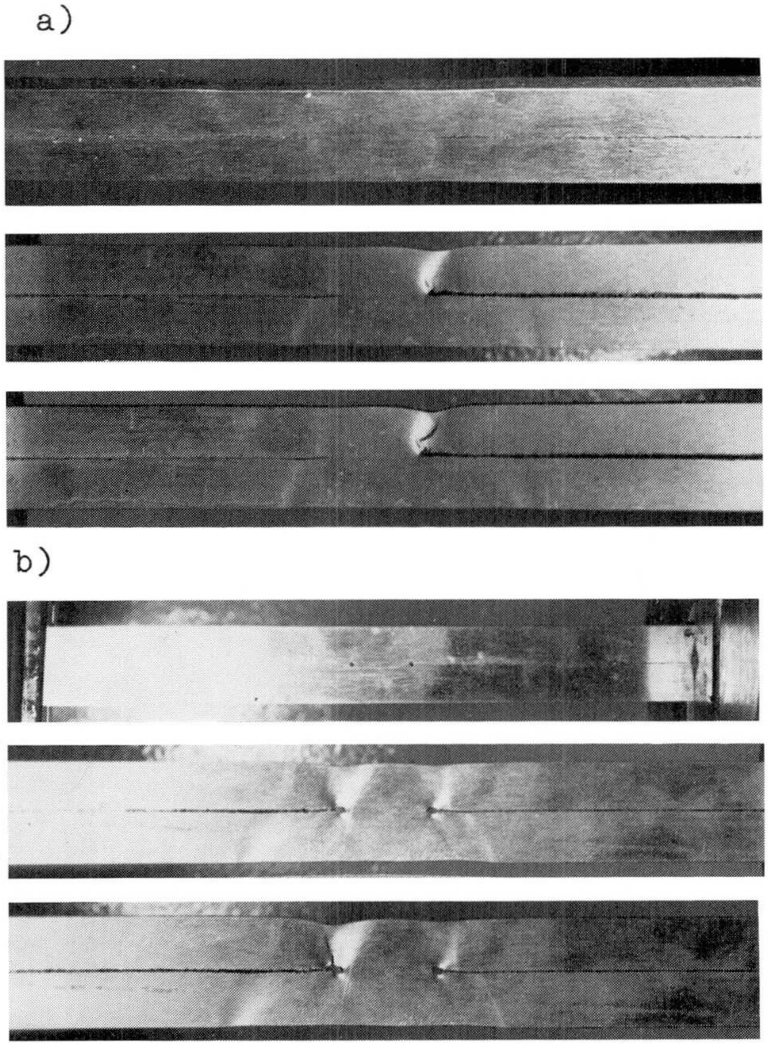

fig. 7. Static tension fracture

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