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**Improvement of Fatigue Life of Welded Beams by TIG-Dressing**

Augmentation de la durée de vie des poutres soudées traitées selon le procédé TIG

Erhöhung der Ermüdungsfestigkeit geschweisster grosser Träger durch WIG-Verfahren

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**SUMMARY**
The fatigue strength of large welded beams has been investigated. The beams were fabricated from StE 460 or StE 690 high strength steel and had either staggered splice details or stiffeners. Some were tested as-welded and others with the weld TIG-dressed. The test results are discussed and compared with results in the literature for smaller beams. The improvement factor of 1.4 to 1.5 obtained by TIG-dressing is lower than that found for smaller beams. In addition, the larger have 20% to 35% less fatigue strength because of welding faults.

**RESUME**
La résistance à la fatigue des grandes poutres soudées a été examinée. Les poutres étaient en acier à haute résistance StE 460 et StE 690 et avaient soit des joints échelonnés, soit des raidisseurs. Quelques unes avaient des soudures brutes, d'autres avaient des soudures traitées selon le procédé TIG. Les résultats des essais sont discutés et comparés avec ceux donnés dans la littérature pour des petites poutres. Le facteur d'augmentation de 1,4 à 1,5 obtenu avec le procédé TIG est plus bas que celui trouvé pour des petites poutres. De plus, les grandes poutres ont une résistance à la fatigue 20 à 35 % plus faible à cause des défauts dans les soudures.

**ZUSAMMENFASSUNG**
Die Schwingfestigkeiten von geschweissten und WIG-nachbehandelten grossen Trägern mit Stumpfstoss und Aussteifungen wurden untersucht. Die Träger waren aus hochfesten Feinkornbaustählen StE 460 und StE 690 hergestellt. Die Versuchsergebnisse werden vergleichend mit denen der ebenfalls untersuchten kleinen Träger und Proben diskutiert. Sie zeigen, dass die Erhöhungsfaktoren WIG-nachbehandelter grosser Träger 1.4 bis 1.5 betragen, was etwas geringer ist als für kleine Träger und Proben. Schweissnahtinnenfehler führen hingegen bei grossen geschweissten und WIG-nachbehandelten Trägern zu einem Schwingfestigkeitsabfall von 20% bis 35%.

## 1. INTRODUCTION

During the last years innumerable investigations of the fatigue behaviour of welded specimens made of different steel grades were carried out. The results showed that there is no or only a little difference between the fatigue strength of low and high strength steels (see literature of reference |1|). Especially concerning high strength steels these findings led to the efforts to find economic and effective methods of increasing the fatigue strength. Besides mechanical treatments of the welds thermic methods seemed to offer more important advantages in terms of efficiency and economy. These methods known as TIG- or Plasma-dressing brought a considerable improvement of fatigue strength up to 170% (see literature of reference |2|).

Nearly all of these investigations were performed on small specimens and only a few were concerned with the fatigue strength of component parts. Beyond that the range of most of the tests was limited and the published results left some questions unanswered. Therefore in 1975 the authors started an extensive research program which dealt with fatigue strength investigations of welded high strength steels in as-welded and TIG-dressed conditions. One of the aims of this research program was to answer the question for transferability of test results from small specimens to larger component parts which is more important for the determination of allowable stresses in design rules and standards.

Essential parts of the whole research program which contains fatigue tests with small specimens, small and larger beams have already been reported |2, 3|. In the following the actual situation of our investigations is presented with special regard to the results of welded larger beams. These results will be compared with those of the smaller beams which are published before |2|.

## 2. TEST MATERIAL, TYPES OF BEAMS AND PERFORMANCE OF FATIGUE TESTS

The investigations were carried out on weldable high strength steels StE 460 and StE 690. The mechanical properties and chemical composition of the used material is shown in Tab. 1. All values are in accordance with the German standard DASt-Richtlinie 011 which regulates the use of weldable high strength steels in static and fatigue loaded structures.

The constant amplitude fatigue tests were performed under four-point bending on two types of welded larger beams, beams with staggered splices and beams with stiffeners, both in as-welded and TIG-dressed conditions. In addition to this rolled beams of steel StE 460 with a butt weld in the top flange and with stiffeners were also tested in aswelded and TIG-dressed conditions. Weld details and dimensions of investigated beams are shown in Fig. 1 to Fig. 4.

## 3. RESULTS AND DISCUSSION OF FATIGUE TESTS

### 3.1 BEAMS WITH STAGGERED SPLICES

The results of larger beams with splices in as-welded and TIG-dressed conditions are shown in Fig. 1 and Fig. 2. They are compared with those of the small beams which are plotted in the unified scatter-band of the S-N-curves for welded |4| and TIG-dressed |2| joints. It can be seen that for the small beams both steel grades have nearly the same fatigue strength. The increasing factor due to the TIG-dressing of the butt welds is about 1,7 which is conform to the improvement of fatigue strength of small specimens with TIG-dressed butt welds |2|.

In case of larger beams the endurable fatigue life is partially much lower than that of the smaller beams. The evaluation of all test results showed that there is a 20% decrease of fatigue strength for both beams in as-welded condition (Fig. 1) and a 35% decrease in TIG-dressed condition (Fig. 2). The main reasons for this lower fatigue life are fatigue crack initiations from TIG-weld porosities or undercuts (Fig. 2) and from the inside of flange butt welds and longitudial fillet welds caused by slag inclusions and hydrogen induced cold cracks (Fig. 1 and Fig. 2). The cold cracks occured only at the longitudial fillet welds of StE 690 beams and were sometimes distributed over the whole weld length.

Only welded beams of StE 460 in as-welded condition which have a normal fatigue crack initiation from the weld toe of the flange butt welds show a tendency to the same fatigue strength as the smaller beams. Not so rolled beams of StE 460 in as-welded condition which have also a normal fatigue crack initiation. Here are the number of cycles comparable with those beams which failed from weld defects (Fig. 1). A possible reason for this fact might be seen in the MAG-welding by hand of the butt welds of rolled beams which produced sometimes a very low weld reinforcement in connection with small base metal undercuts.

Larger beams in TIG-dressed condition show only a small improvement of fatigue life due to the very high number of failures inside the welds (Fig. 2). As mentioned in former publications |2, 3| a successful utilization of the TIG-dressing is ony given if the dressed welds have neither systematic inner notches nor larger inner faults and porosities or undercuts of the TIG-weld. Otherwise the fatigue crack starts at these faults and the TIG-dressing process produces no or only a little effect. Therefore the increasing factor in the present case is lower than for the smaller beams and reaches only a value of about 1,4.

## 3.2 BEAMS WITH STIFFENERS

Fig. 3 shows the results of beams with stiffeners in as-welded condition. In contrast to the larger beams the results of smaller beams plotted in the unified scatter band of the S-N-curve for welded joints |4| have no uniform fatigue strength for both steel grades. The difference in the endurable fatigue limit stresses between smaller beams of StE 460 and StE 690 is about 50%. Reasons for this discrepancy are unknown. Influences of residual stresses which could not be removed by post-weld heat treatment are possible.

The fatigue strength of larger welded beams, however, is nearly the same for both grades of steel and within the scatter of the small beams. Only the slope of the S-N-curve seems to be a little bit steeper and therefore not in accordance with the given slope $k_{50\%} = 3,75$ of the statistical evaluation. Here again larger rolled beams have a lower fatigue life than larger welded beams although all investigated beams had a normal fatigue crack initiation from the weld toe of the stiffener welds.

The results of stiffened beams in TIG-dressed condition are presented in Fig. 4. In contrast to the fatigue behaviour of small beams in as-welded condition (Fig. 3) we can see a similar fatigue strength of TIG-dressed small beams for both grades of steel. Only the limit number of cycles $N_A$ which for TIG-dressed joints is normally given at $10^6$ cycles could be shifted to a value of $2 \cdot 10^6$ cycles. This decrease of fatigue limit stresses seems to be caused by small undercuts of the TIG-weld run. The increasing factors are about 1,5 for StE 690 and 2,4 for StE 460 if the limit number of cycles $N_A = 10^6$ for TIG-dressed beams is compared with $N_A = 2 \cdot 10^6$ for as-welded beams. The latter increasing factor of 2,4 results from the very low fatigue limit stress of small StE 460 beams in as-welded conditions (Fig. 3).

The evaluation of all test results of larger beams in TIG-dressed condition show a decrease of the endurable fatigue strength of about 30%. For the larger welded beams of StE 460 also undercuts lead to a lower endurable fatigue life. Here the TIG-welds have undercuts with a greater depth than for the smaller beams. Rolled beams of StE 460 with normal fatigue crack initiations from the transition between the base metal and the TIG-weld run have a better fatigue life behaviour which is near to the lower limit of the scatter-band of the small TIG-dressed beams. In case of larger welded StE 690-beams again the fatigue cracks initiate at the inside of the longitudial fillet welds but they are still in the range of StE 460-beams.

## 3.3 COMPARISON WITH SMALL SPECIMENS

As mentioned before one of the aims of the investigations was to answer the question of transferability of fatigue data from small specimens to larger component parts. In Fig. 5 and Fig. 6 the test results of small and larger beams are compared with those of the specimens both in as-welded and TIG-dressed condition. The endurable stress amplitudes $\sigma_A$ of all investigated test series and stress ratios are plotted in the Haigh-diagram verse the mean stress $\sigma_m$. For the comparison the fatigue limit stresses $\sigma_A$ of as-welded joints are related to $N_A = 2 \cdot 10^6$ number of cycles and for TIG-dressed joints to $N_A = 10^6$ cycles.

Joints with butt welds (Fig. 5) show a very good conformity of small specimens and small beams. Influences of the Steel grade or the type of specimen are hardly evident. The TIG-dressing process produces a considerable improvement of fatigue strength with no difference between small specimens and small beams. The increasing factors are nearly independent of the stress ratio and have a mean value of about 1,6 which is comparable with other international investigations (see references of literature in |2|). As-welded and TIG-dressed joints have similar mean stress dependences. Larger beams, however, which were only investigated at a stress ratio R = 0,1 do not confirm these statements. In as-welded condition they have a 20%-decrease of fatigue strength in comparison with the small beams and in TIG-dressed condition the decrease is about 35%. The reasons for this fact are weld defects inside the longitudial fillet welds and the flange butt welds which bring especially in case of dressed larger beams a very low fatigue strength. Due to this the increasing factor of dressed larger beams is only 1.4 (see chapter 3.1).

In contrast to the joints with butt welds joints with stiffeners have no uniform fatigue strength behaviour (Fig. 6). As-welded small specimens of both steel grades differ in the range of R = -3 up to R = 0,4. Possible reasons for this fact might be seen in residual stress influences as well as in the specimen geometry |2|. Small beams with stiffeners show similar fatigue limit stresses for the stress ratio R = 0,1 as the small specimens. In case of TIG-dressed small specimens only the steel StE 690 was investigated. Here a change of the crack initiation from the transition between the base-metal and TIG-weld run to the weld root under the stiffener shifted the limit number of cycles $N_A = 10^6$ to a value of about $N_A = 2 \cdot 10^6$ coincident with lower endurable fatigue stresses |2|. Therefore the increasing factors of TIG-dressed small specimens with stiffeners made of StE 690 reach only a mean value of about 1,4 which is nearly the same for small StE 690-beams with stiffeners. TIG-dressed small beams of StE 460, however, have an increasing factor of about 2,2 which is caused by the very low fatigue limit stresses of beams in as-welded condition.

Larger beams with stiffeners in as-welded condition show the same fatigue strength as the small StE 460-beams. In both cases the fatigue crack started at the weld of the stiffener welds. In TIG-dressed condition the endurable fatigue stresses of larger beams are much lower than those of comparable smaller beams. Responsible for this decrease which is about 30% are again failures inside the longitudial welds of StE 690 beams (cold cracks) and TIG-weld undercuts of StE 460 beams. Therefore the increasing factor is only 1,50 (see chapter 3.2).

## 4. CONCLUSION

The present investigations were performed on larger welded beams of high strength steels StE 460 and StE 690 and on a small number of larger rolled beams of StE 460 both with staggered splices and with stiffeners in as-welded and TIG-dressed conditions. The results of the fatigue tests made clear that problems arised not only by the welding but also by the TIG-dressing of high strength steels in larger dimensions under normal service conditions.

The main welding problem, hydrogen induced cold cracks, occured although the choice of the welding parameters |3| was done with attention to the particular specifications of the steel StE 690. These cracks lead to a decrease of the endurable fatigue life which was pointed out by the present fatigue tests. On the other hand TIG-dressing with undercuts produces only a little increasing effect as shown by the test results of StE 460 beams. Due to these reasons the endurable fatigue limit stresses of larger beams in as-welded and TIG-dressed conditions decrease for the investigated stress ratio R = 0,1 between 20% and 35% in comparison with the smaller beams. The increasing factors of TIG-dressed larger beams reached only values of 1,4 and 1,5 which is lower than those of the small beams and comparable small specimens |2|. The above mentioned reasons, cold cracks and TIG-weld undercuts, can be avoided by changing of the welding parameters and a better manual technique of TIG-dressing.

To sum up it can be said that in general the fatigue strength is evidently increased by the TIG-dressind process. As the test results showed this is not only valid for small specimens but also for larger component parts. Therefore the possibility of higher design stresses of TIG-dressed joints is given.

## REFERENCES


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| Steel grade | C % | Si % | Mn % | P % | S % | N % | Al % | Cr % | Cu % | Ni % | Mo % | V % | Zr % | $\sigma_y$ N/mm² | $\sigma_{UTS}$ N/mm² | $\delta_S$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| StE 460 | 0,17 | 0,35 | 1,52 | 0,017 | 0,007 | 0,015 | 0,025 | 0,01 | 0,01 | 0,58 | 0,02 | 0,13 | - | 480 | 630 | 30 |
| StE 690 | 0,15 | 0,58 | 0,93 | 0,014 | 0,011 | 0,009 | 0,048 | 0,78 | 0,11 | 0,09 | 0,26 | 0,02 | 0,10 | 770 | 830 | 21 |

Tab. 1 Chemical composition and mechanical properties of investigated steels

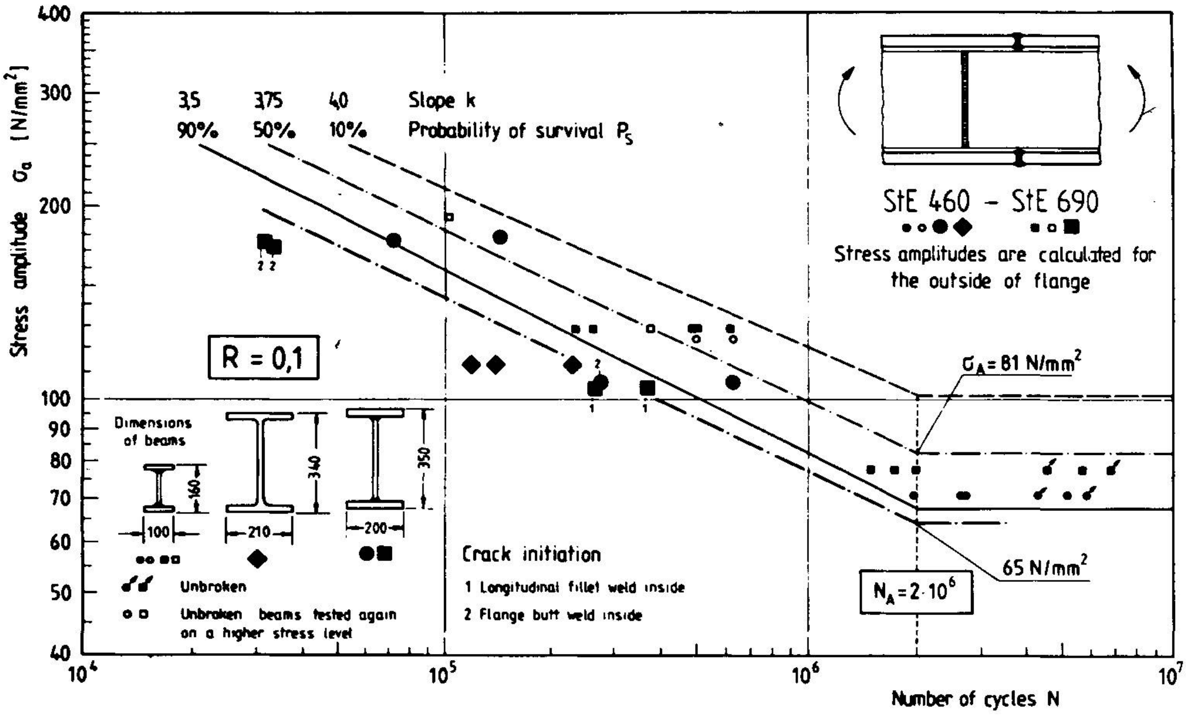


Fig. 1 S-N-curve for welded high strength steels-Beams with staggered splices

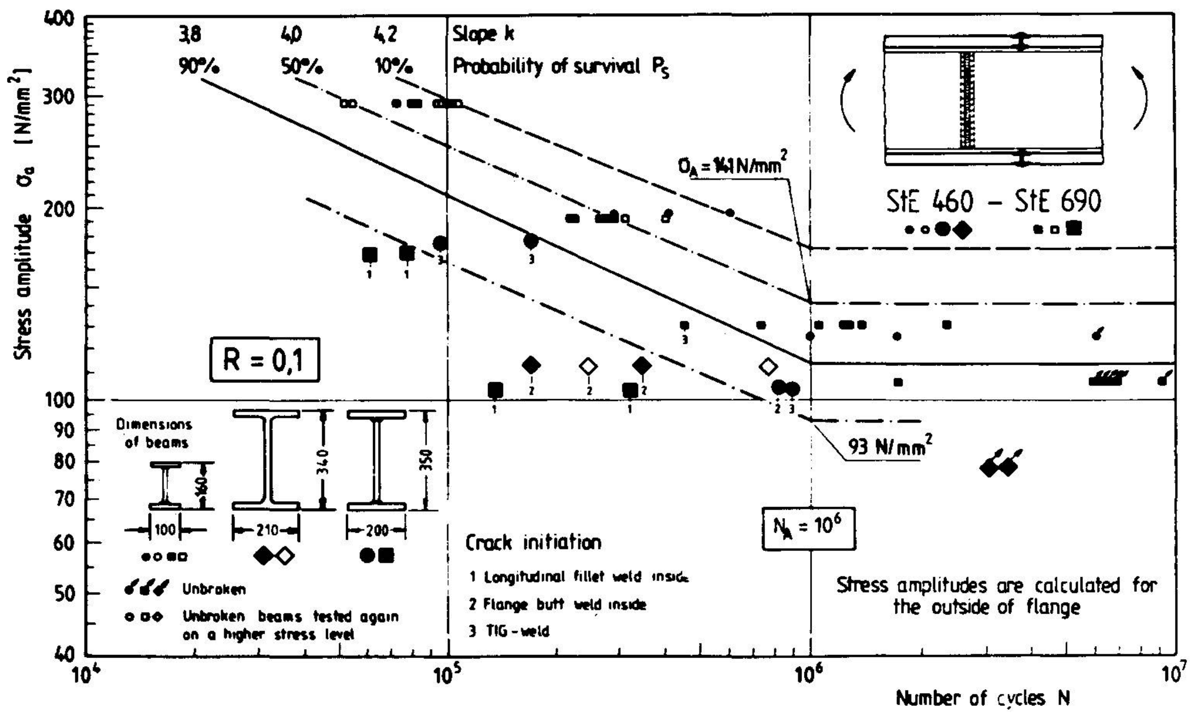


Fig. 2 S-N-curve for TIG-dressed high strength steels-Beams with staggered splices

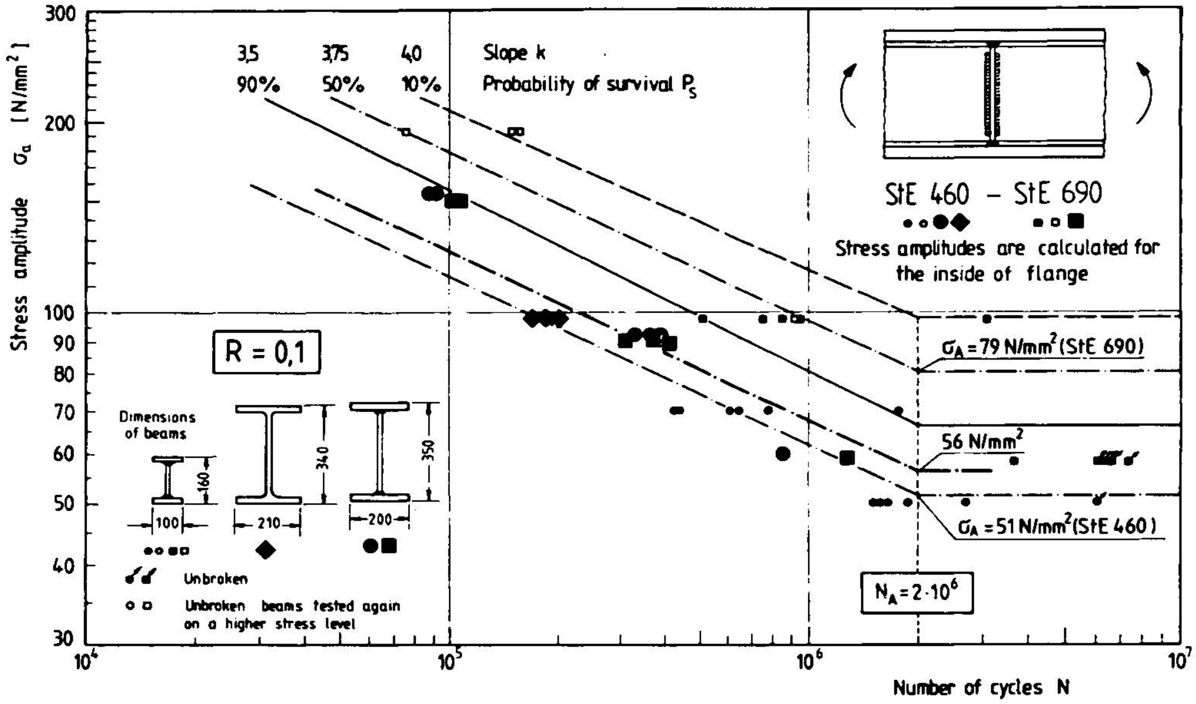


Fig. 3 S-N-curve for welded high strength steels-Beams with stiffeners

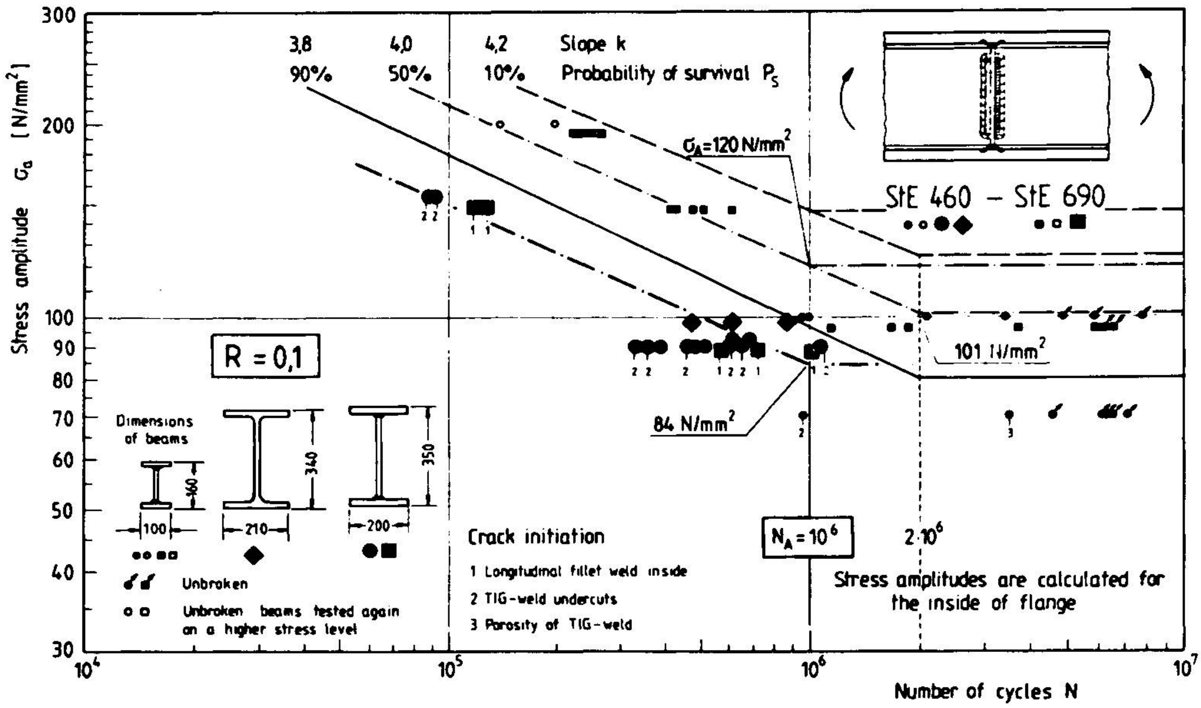


Fig. 4 S-N-curve for TIG-dressed high strength steels-Beams with stiffeners

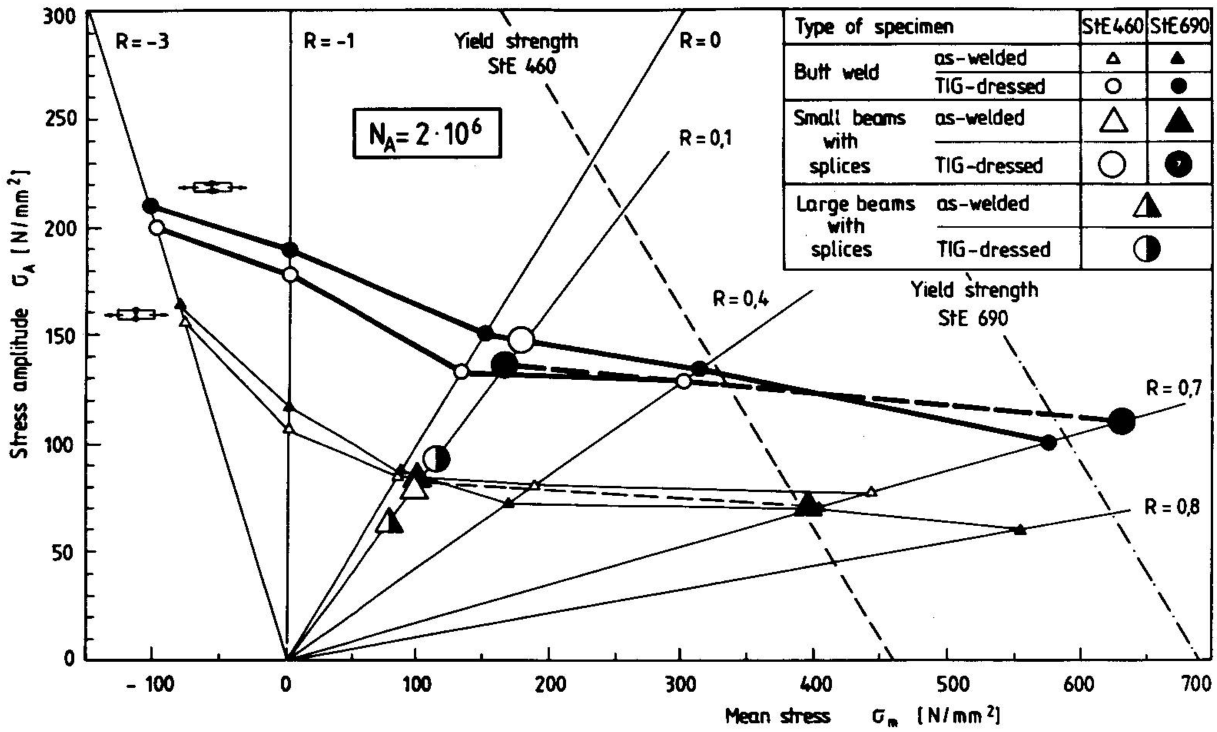


Fig. 5 Comparison of as-welded and TIG-dressed specimens - Joints with butt welds

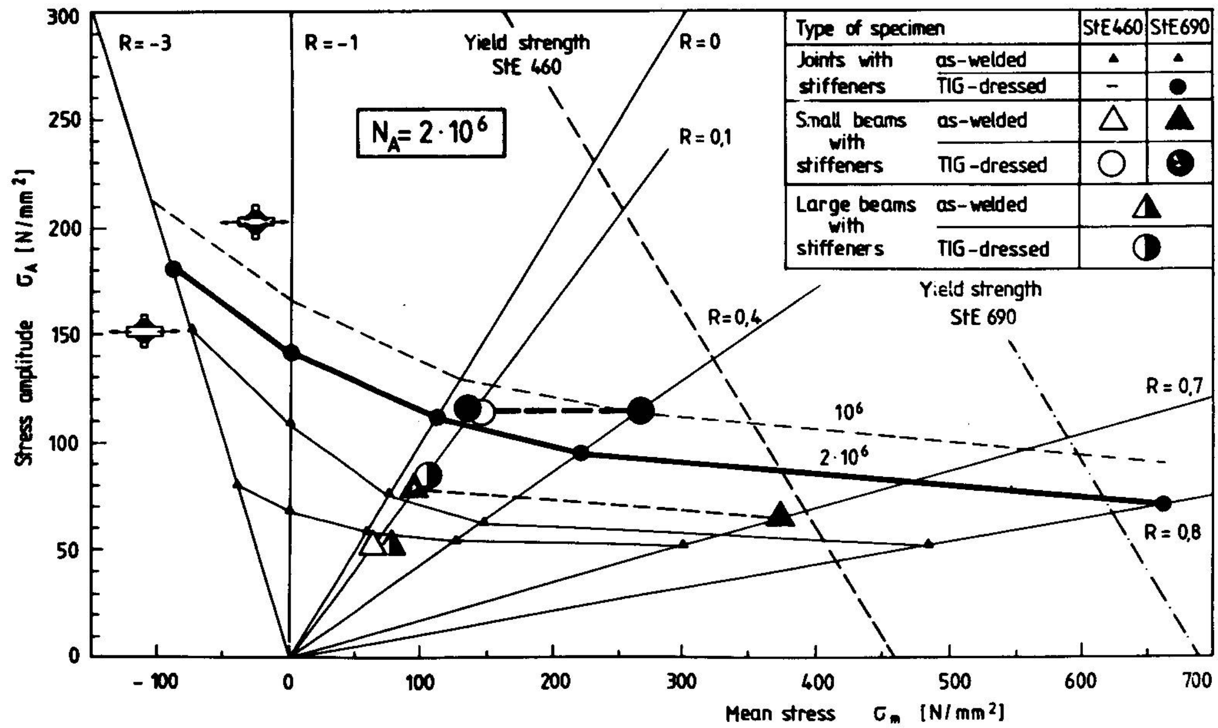


Fig. 6 Comparison of as-welded and TIG-dressed specimens - Joints with stiffeners