Special Lecture

Plastic Deformation Behaviors in the Longitudinal Butt Welded Joints between High Strength Steel and Mild Steel

by

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As well known, the general trend toward a mammoth size in steel structures such as ships and bridges has brought about remarkably increasing the use of high strength steel. It would not be too much to say, in this connection, that the application of high strength steel to mammoth structures is aimed at maximizing their allowable stress in designing and at reducing their weight as a whole by the use of high strength steel in specific critical parts rather than in the whole of the structure. The examples of hybrid structure are the uses of mild steel in the side plating and of high strength steel in the upper deck or in some strength members of the double bottom structure of large ship, and the uses of mild steel in the webs and of high strength steel in the flanges of H-shaped girder of bridge with long span, etc. In some cases, the dissimilar steels are, as a matter of general practice, jointed by welding.

I made clear the presence of significant differences in the plastic strain behavior between mild steel and high strength steel under tensile loading [1]. Fig. 1 shows the nominal stresselongation curves obtained as a result of static tensile tests for the annealed base metal of SM41(ultimate tensile strength is 41 kg/mm^2) and HT60(ultimate tensile strength 60 kg/mm^2). It seems from the figure that the elongation in HT60, which is developed at the maximum load, is lower than that in SM41. Plastic strain was analyzed by Moiré method to compare the distributions of strain in those steels, and the results are given in Fig. 2. The figure indicates the longitudinal distributions of strain at the various stages of tensile loading, which shows the strain distributions along the longitudinal distance of 48mm including the position of fracture D in the center. For SM41, the distribution of strain, up to the maximum nominal stress of 41.6 kg/mm^2, is nearly even in the longitudinal direction as shown in Fig. 2 (a). After the nominal stress attains to the maximum, the strain becomes maximum at D with the necking. Meanwhile, the strain in HT60 grows at D before attainment of the maximum nominal stress of 58.5 kg/mm^2 as shown in Fig. 2 (b), and then the necking occurs before the load reaches the maximum. After attainment of the maximum nominal stress of 58.5 kg/mm^2, the strain becomes increasingly concentrated at D, while the strains at A and G which are located 24mm from the position of fracture grow only little. Therefore, it may be noted that the total elon-

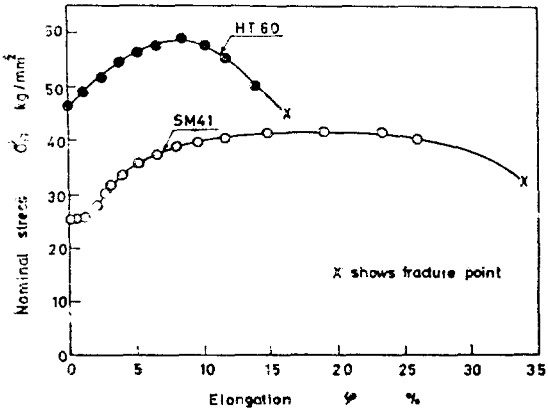

Fig. 1

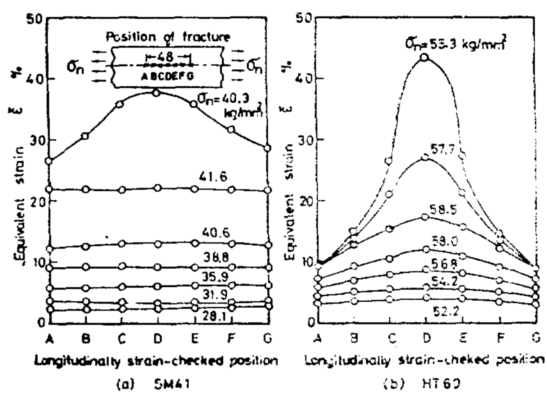

Fig. 2

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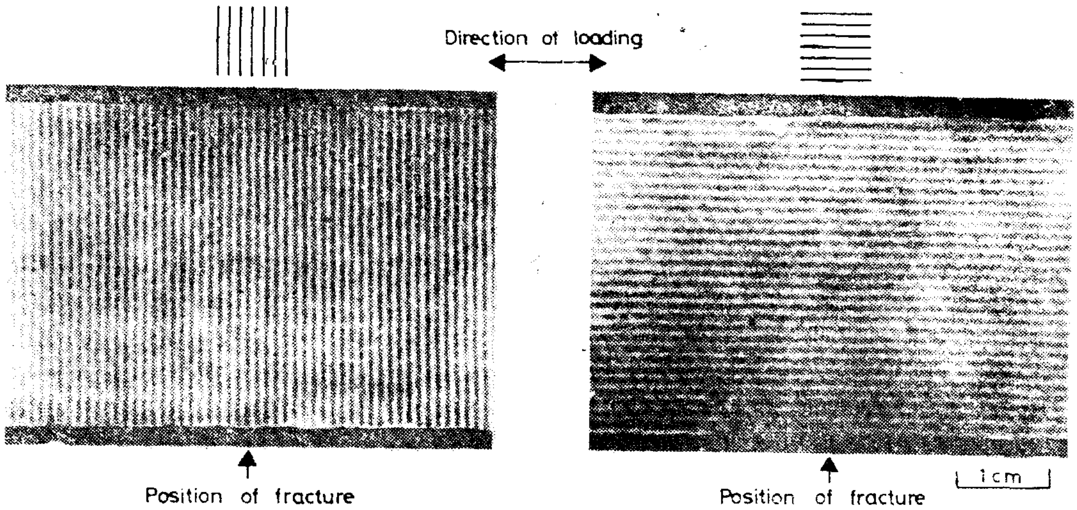


Photo. 1

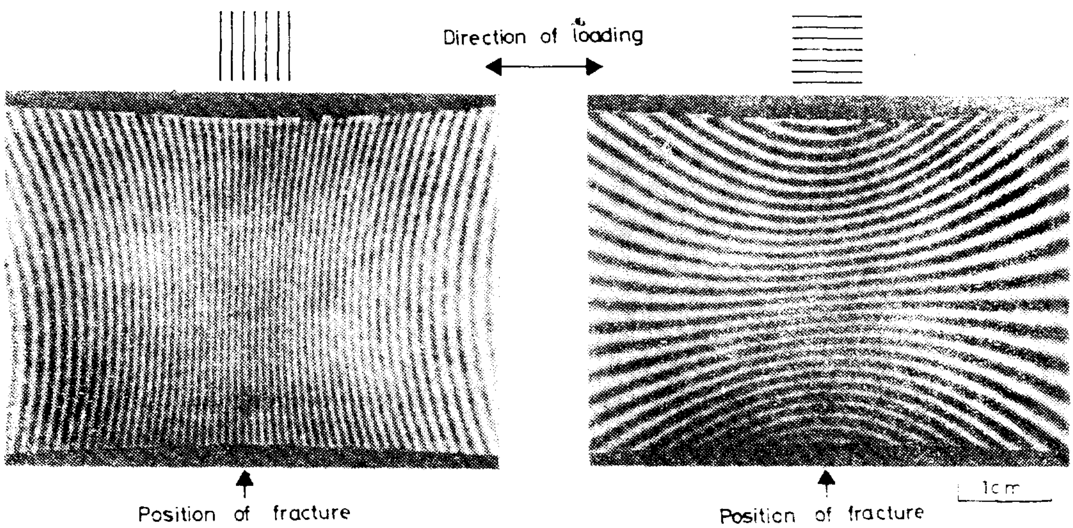


Photo. 2

gation of HT60 in the tensile test is given mainly by that of the portion where strain concentration takes place, and in other words that in HT60 the strain at a short distance from the position of fracture contributes less to the total elongation than in the case of SM41. Photo. 1 and 2 show the Moiré fringes of the matching condition in SM41 and HT60 at their respective maximum nominal stress. Photo. 1 shows the Moiré fringes in SM41 forming a group of equally spaced parallel lines and then the strain distributes quite evenly. However, Photo. 2 reveals the fringes in HT60 bending conspicuously to crowd at the position of fracture where the strain concentrat[illegible].

Therefore, in structural members built up by welding together SM41 and HT60, the above-mentioned differences in their respective strain behavior are presumed to greatly affect the strength of the composite weldments. With respect to this problem, it may be accepted basically with two typical composite weldments as shown in Fig. 3. Fig. 3(a) is the case of loading perpendicular to the weld line, Fig. 3(b) the case of loading parallel to the weld line. In both cases, the material in part I is dissimilar to that in part II. The former was studied by Bakshi[2] and Satoh[3]

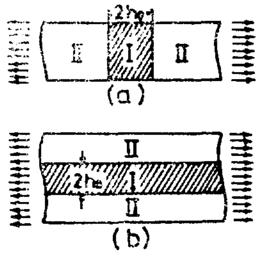
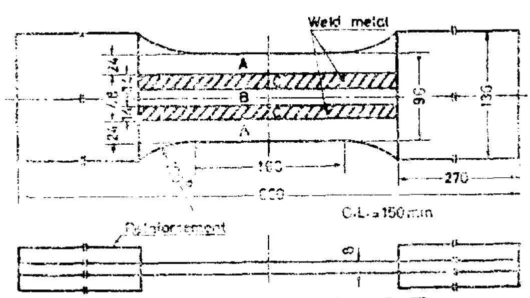


Fig. 3

respectively. It may be expected qualitatively from their results that when the strength of material in part I is higher than that in part II. the strength of composite weldment is almost equal to that of material itself in part II because the fracture occurs at part II. And when the strength of material in part I is lower than that in part II, the strength of composite weldment increases to that of material itself in part II with decreasing the width of part I in spite of the fracture in part I. The increasing of tensile strength of composite weldment depends upon the difference of strength between two materials, and is attributable to the constraint of plastic deformation in part I. In any case, these types of composite weldment fail in the soft metal with low strength. However, in latter case shown in Fig. 3(b), it is interesting that the fracture initiates in the hard metal with high strength as described after.

Therefore I would like to talk about the composite weldments subjected to static tensile load in the direction of weld line. The plain specimens with composite weldment are shown in Fig. 4. The HSH specimen has HT60 on both sides and SM41 in the middle, and



Speci.code	A	B	C
HSH	HT60	SM41	SM41 Electrode
SHS	SM41	HT60	HT60 Electrode

Fig. 4

the SHS specimen is oppositely arranged. All the reinforcement of welded joints were removed by machining. The total width of both sides is equal to that of the middle including the weld metal. The measuring points of strain are shown in Fig. 5. Fig. 6 indicates the comparison of the longitudinal distributions of strain at the various points of the HSH and SHS specimen. In any specimens, the strain on the SM41 side increases almost evenly before the nominal stress reaches the maximum, while that on the HT60 side shows a tendency to concentrate slightly on the position of fracture. This strain concentration on the HT60 side is smaller as compared with that of the HT60 base metal itself shown previously in Fig.2(b). It can be understood that the specimens of composite weldment apparently show total elongation close to that of the SM41 base metal itself. After the nominal stress reaches the maximum, fairly great strain concentration occurs on the HT60 side and the fracture takes place there in both specimens as shown in Photo. 3.

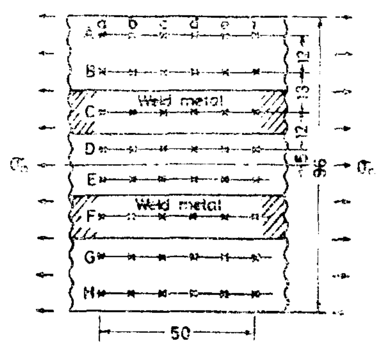
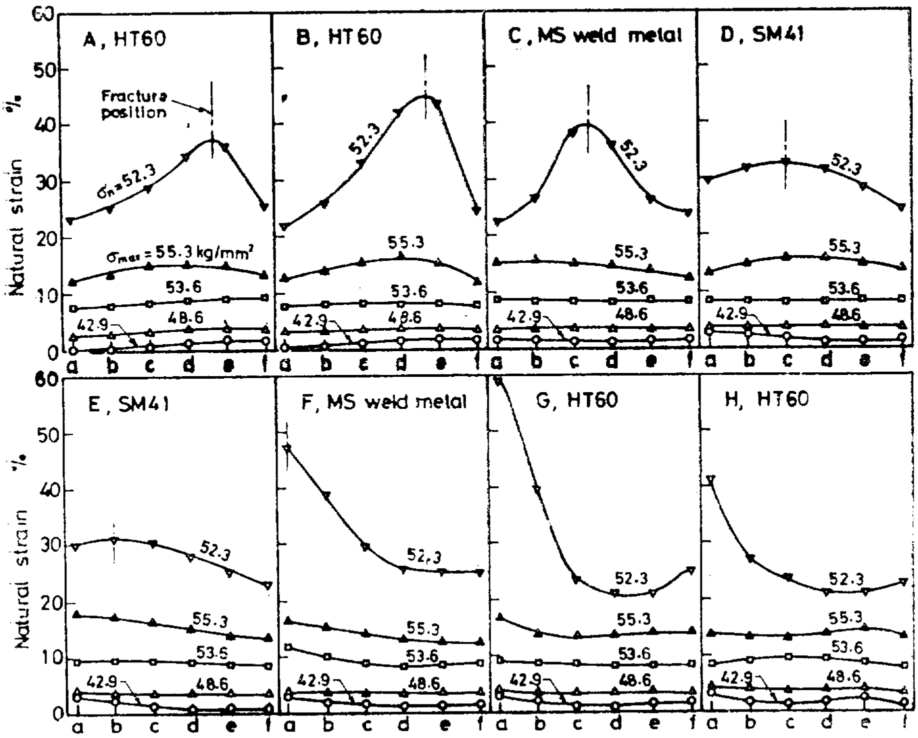
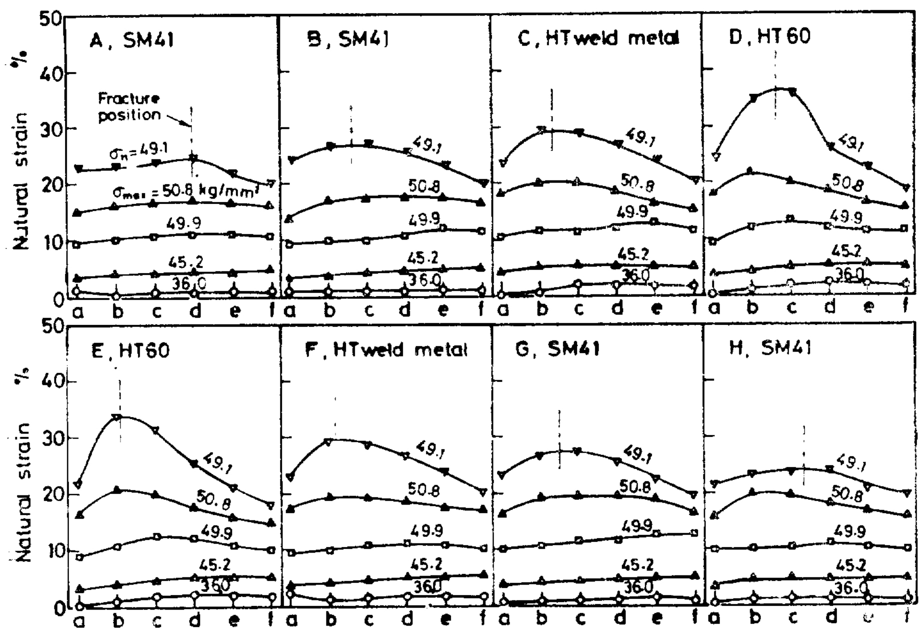


Fig. 5

Since conspicuous strain concentration is identified on the HT60 side of the plain specimens of composite weldment, U-notches were provided on both sides so as to permit easier occurrence of strain concentration, and the degree of such concentration was checked on the HSH and SHS specimen. The notched specimens with composite weldment are shown in Fig. 7. The total width of both sides at the notch root section is equal to that of the middle including the weld metal. Fig. 8 shows the nominal stress-elongation curves for the HSH and SHS specimen. The SHS specimen with notches in the soft metal SM41 is superior in ductility



(a) HSH speci.



(b) SHS speci.

Fig. 6

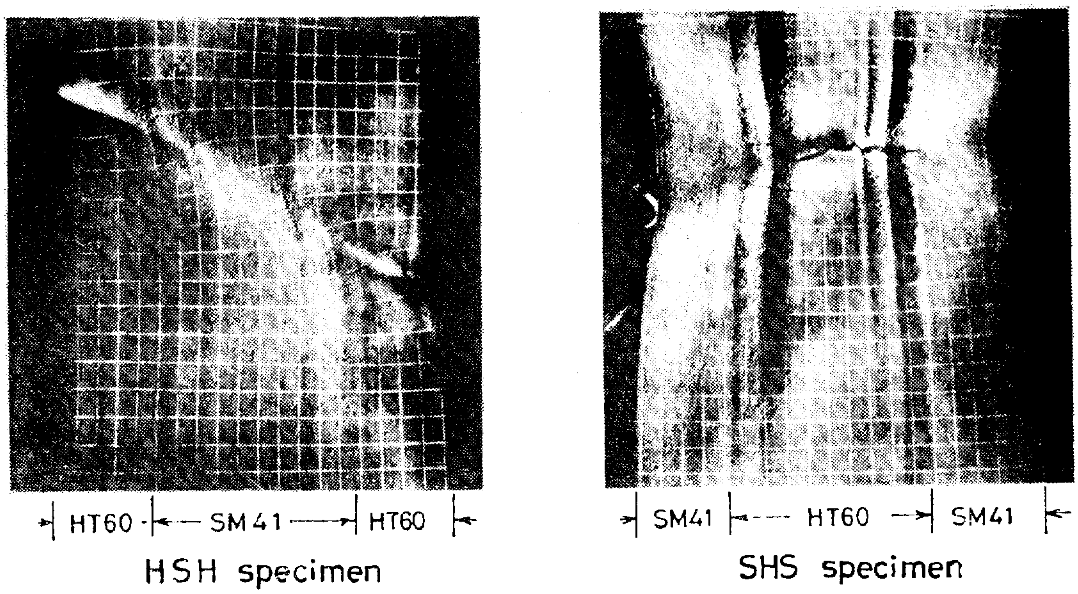
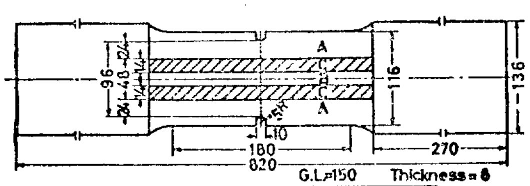


Photo. 3



Speci. code	A	B	C
SHS-U	SM41	HT60	HT60 weld metal
HSH-U	HT60	SM41	SM41 weld metal

Fig. 7

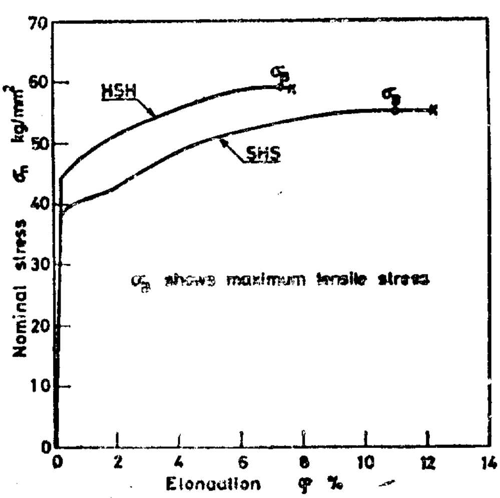
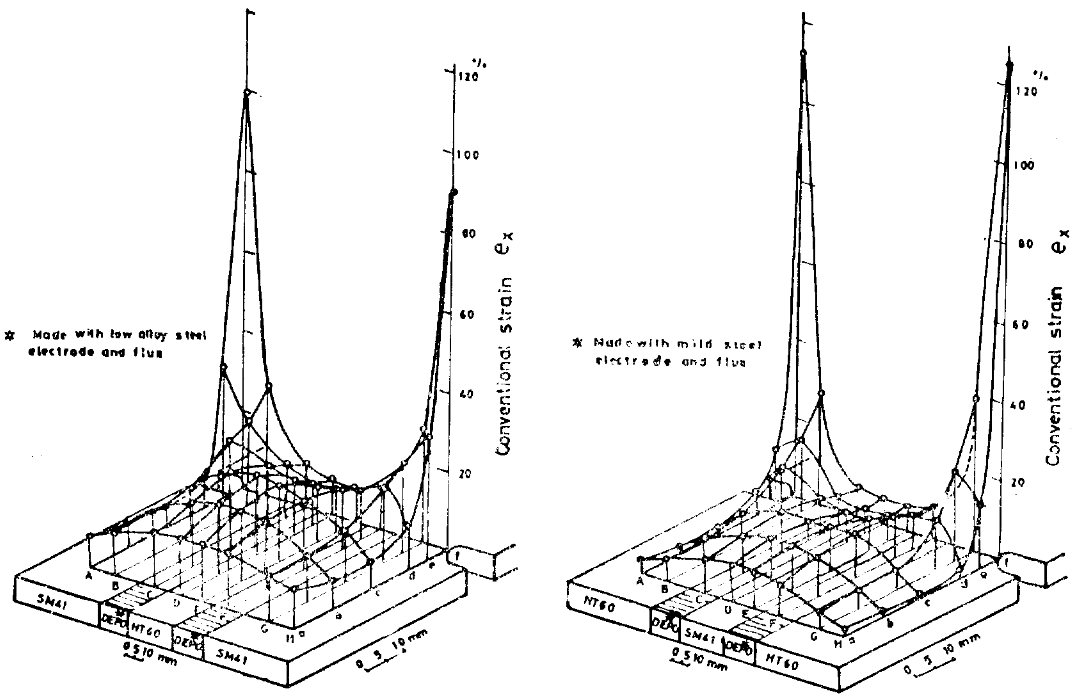


Fig. 8

to the HSH specimen with notches in the hard metal HT60. Fig. 9 indicates two dimensional distributions of the axial strain at the maximum load on the SHS and HSH specimen. It is known from the figure that the strain at the root of notches is larger in the HSH specimen than in the SHS specimen, while the strain at the portion apart from the notches has the opposite tendency. That is, the strain concentration is more remarkable on the notch of HT60 sides of the HSH specimen than on that of SM41 sides of the SHS specimen. Photo. 4 shows the Moiré fringes on the specimen of composite weldment arranged asymmetrically SM41 and HT60. The fringes closely crowds at the notch root of the HT60 side. The fact indicates that the strain is particularly concentrated in this portion.

The stress distributions at the notch root section obtained by strain increment theory are shown in Fig. 10. The figure shows that the stress abruptly increases in the middle of the SHS specimen after the yielding occurs at the notch root. Since the stress redistribution takes place on the SHS specimen, the stress concentration at the root of notches is lower after the SM41 sides begin yielding. On the contrary, the stress redistribution does not occur on the HSH specimen.



(a) SHS specimen (b) HSH specimen

Fig. 9

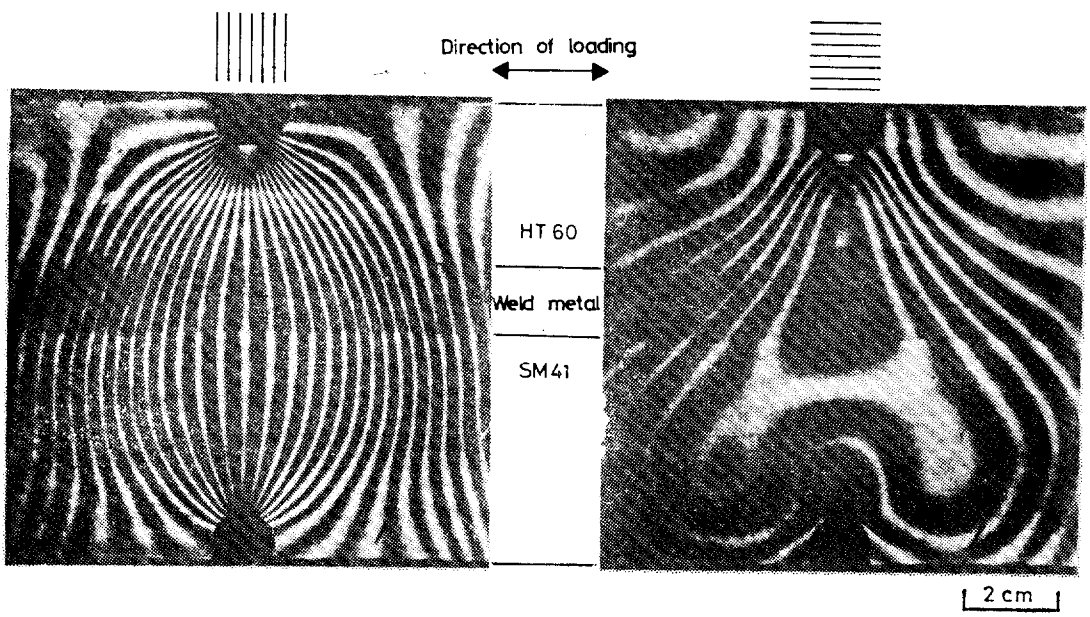


Photo. 4

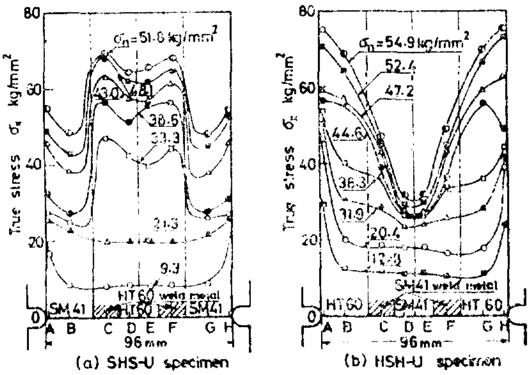


Fig. 10

From the above difference in tendency of strain concentration, it can be said that we should be careful about the material arrangement in hybrid structures. And we must leave the problems of low cycle fatigue and brittle fracture in hybrid structures for a future study.

References

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〔3〕 K. Satoh and M. Toyoda ; "Static Tensile Properties of Welded Joints Including Soft Interlayer", *Trans. of J.W.S.*, 1, 7-12, 1970