Fatigue behaviour of Welded Joints of Structural Steel

By N. D. DAS*

ABSTRACT

The paper documents the results of fatigue tests carried out on welded samples of IS : 226 *grade structural steel. The endurance limit of the welded joints under test conditions was found to be approximately* 8.7 *tons/sq. in.*

INTRODUCTION

All components subjected to cyclic stresses suffer from damage due to fatigue. The extent of damage depends upon the range of cyclic stresses and number of cycles. At higher level of stresses close to the yield point, damage is rapid and the material fails by progressive fracture within a short period of its life. With the lowering of stress range, the life of the material under cyclic stresses also increases and a level is reached at a stress range when the material shows 'infinite' life i.e. it does not fail even after prolonged tests. This particular range of stresses is then termed the 'endurance limit' of the material under a particular set of conditions.

Endurance limit is affected by
(i) the pattern of stresses (ii) level of mean stress (iii) Degree of pre-stress (iv) Surface finish (v) Extent and nature of residual stresses (vi) Presence of stress raisers (vii) Environmental conditions (viii) Frequency of stress cycles etc.

Even for a particular type of material, the endurance limit is very much influenced by variations in chemistry, metallurgy and method of its manufacture.

In the present work. attempts have been made to obtain an idea of endurance limit of welded joints of structural steel prepared by manual metal arc welding process. The most vulnerable area in a welded joint is HAZ (heat affected zone) from where fracture will start. The investigation was undertaken with a view to generating fatigue data on structural steel welded joints which would be ultimately useful to the designers and fabricators.

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Type of Material

The material chosen for this work was steel of IS : 226 designation which is widely used for general purpose structural fabrication. Thickness of the material was 15 mm.

Chemical composition and mechanical properties are shown in Table 1.

Table 1

Chemical composition

Constituent —	Wt. % max.
Carbon	0.23
Sulphur	0.055
Phosphorous	0.055

Mechanical Properties

Tensile strength	42-54 kgf/mm^2
Yield strength	26 Kg/mm^2
% Elongation (on $5.65\sqrt{S_0}$)	—23%
Bend test	Satisfactory.

Samples were welded without pre and post weld heat treatment. D.C. power source with straight polarity was used. Electrode current was 100 amp. and electrode diameter was 2.5 mm. The type of electrode was E 6013. The edge preparation was 80° groove angle.

Testing Equipment

The machine used for fatigue tests was a Pulsator Fatigue Testing Machine (as shown in Fig. 1). It is a push-pull dual mass resonance type fatigue testing machine. The dynamic force was introduced by an oscillating system comprising of a helical spring oscillated by an out-of-balance rotor, which builds up the oscillation of the spring to the required alternating load. Operation of the machine was carried out on the rising portion of the resonance curve and not on the peak. A further helical spring was employed to apply initial static loads to the test specimen. It was thus possible to superimpose an initial tensile or compressive static load on the alternating load.

Both static and dynamic loads were measured by a loop dynamometer fitted with a microscope through which the amplitude of deflection of dynamometer was measured by means of an illuminated slot diaphragm and graticule.

Preparation of test pieces

Several numbers of plate of size 380×215×15 mm were welded taking two at a time and in transverse direction. They were cut to make test pieces so that welded portion remained at the middle of test specimen. Test specimens (Fig. 2) were prepared by milling, grinding and finally, finishing by polishing with 0—0 grit emery paper. Grinding was done for all specimens by same grinding wheel having same grit and grade.

Measurement of surface finish of the specimens : Surface finish of the flat face of the specimens was measured with the Talysurf. The profile of the surface finish obtained is shown in the Fig. 3.

Sequence of operation during experimentation

The following sequence of operations was maintained during experimentation.

(1) Appropriate grip holders were fitted to the machine by means of four large bolts in each.

(2) The dynamometer cross head was wound back by means of hand wheel to enable the specimen to be inserted.

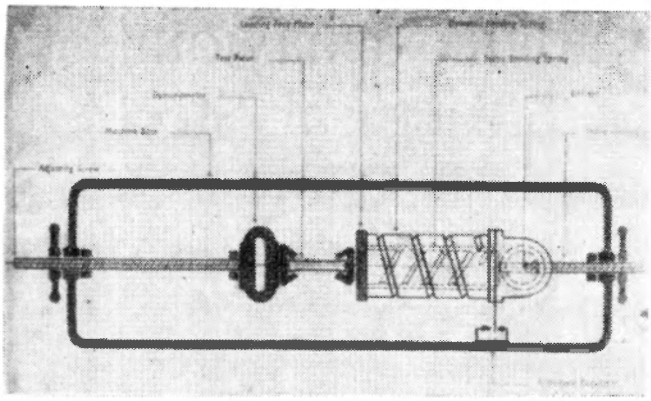


Fig. 1. Pulsator fatigue testing machine.

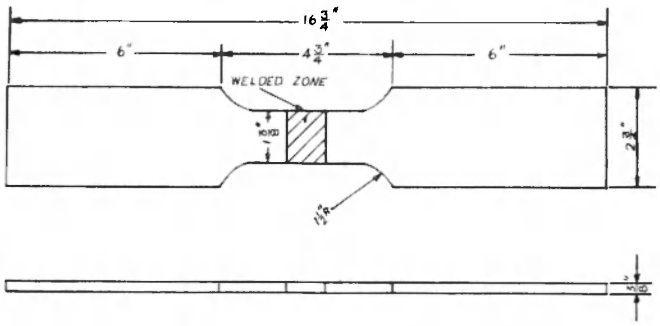


Fig. 2. Test specification.

Fig. 3. Profile of the surface finish of the flat face of the specimen.

(3) Illumination for the microscope was switched on and initial reading of microscope and counter were taken.

(4) The crosshead was adjusted in such a way that the specimen was fully engaged in the grips. Care was taken to see that the specimens were centrally and vertically disposed.

(5) Static load was set by reading off the calibration graph the value in divisions for the load desired.

(6) The Motor-generator was started and D.C.Driving motor was switched on. The amplitude of oscillation was adjusted by means of the regulator until the microscope indicated the number of divisions which corresponded with the desired pulsating load.

TABLE II

Stress Range in Tons.					
Static load in tons	*Pulsating load in tons.*	*No. of test pieces tested*	*No. of test pieces broken*	*No. of cycles endured in millions*	*Remarks.*
3 Tons tension	± 3	2	2	(a) 0.7 (b) 0.63	(a) The sample broke at HAZ. (b) Samples was broken at welded joint. It was found defective at welded portion.
3.5 Tons tension	± 3	2	2	(a) 0.6 (b) 0.55	Both the samples broke at HAZ.
2.5 Tons tension	± 2.5	2	2	(a) 1.05 (b) 1.04	Both the samples broke at HAZ.
2.75 Tons tension	± 2.75	2	2	(a) 0.6 (b) 0.65	-do-
2.25 Tons tension	± 2.25	2	2	(a) 4.01 (b) 4.05	Sample was not broken.
2.25 Tons tension	± 2.25	2	—	(a) 5.05 (b) 5.10	-do-

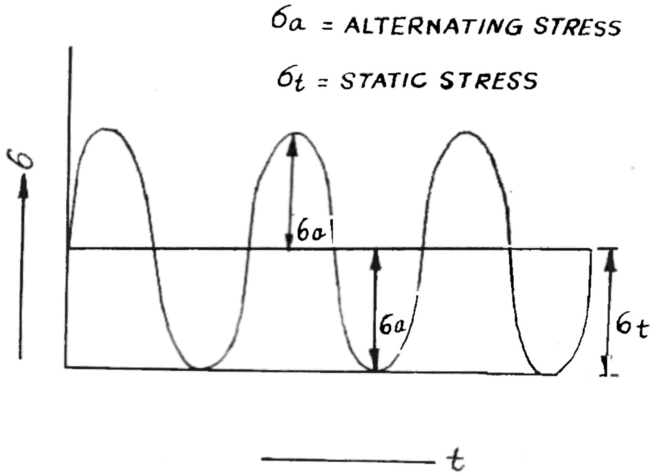


Fig. 4. Pattern of cyclic loading.

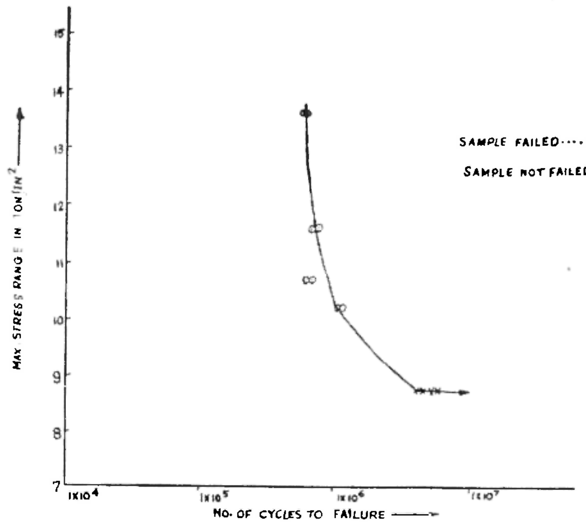


Fig. 5. (S-N) curve.

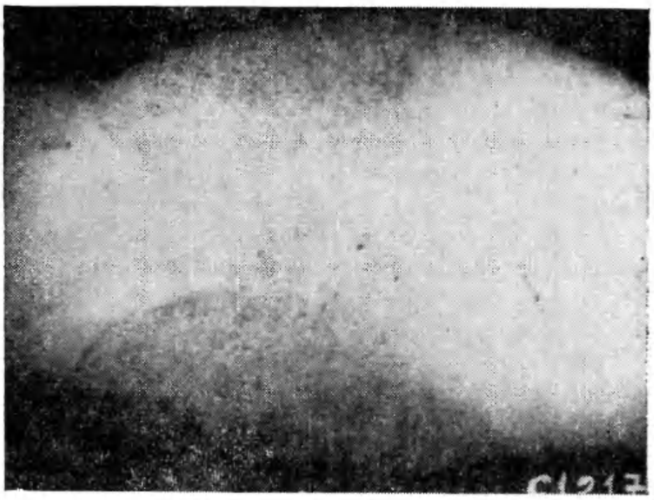
Test Data

A total of 12 specimens prepared in the above manner were tested at different stress ranges. Details of test results obtained are given in table II. The pattern of the cyclic loads are shown in Fig. 4.

(S—N) curve drawn on a semilog paper with the test data is shown in Fig. 5.

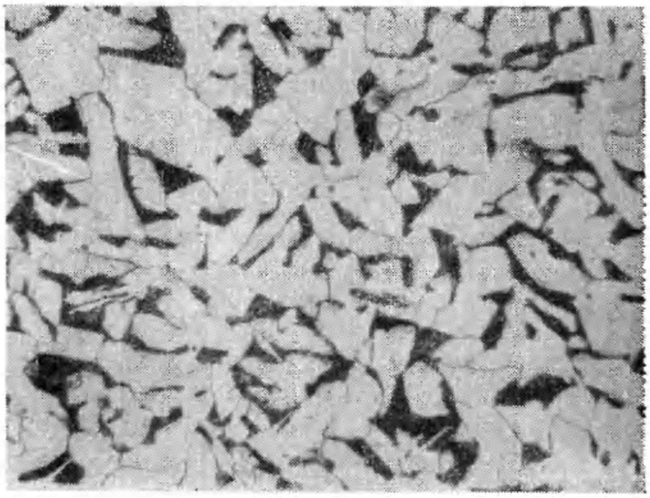
Metallurgical Investigation of the sample

Generally a welded specimen contains three zones viz. base metal, heat affected zone and weld metal. Fig 6 shows the macrophotograph of the joint ; microstructure of the base metal is shown in Fig. 7. It appears from the



Magnification-10×

Fig. 6. Macrophotograph of the joint. It appears ftom the macrophotograph that it contains columnar structure of weld metal in the outer portion of the weld.



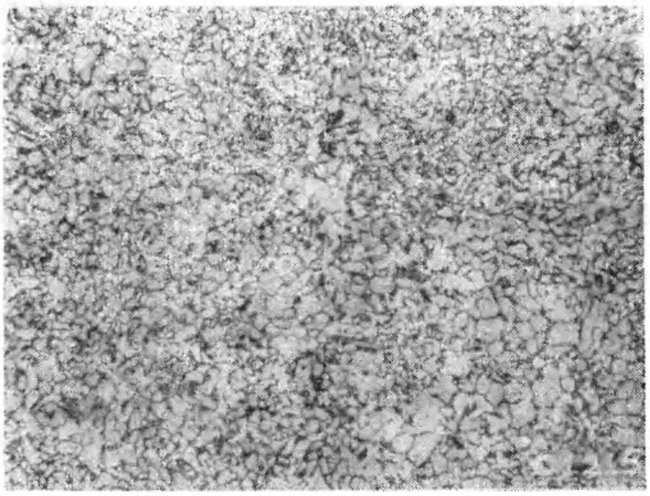
Magnification-300×

Fig. 7. Macrophotograph of base material. It appears from the macrophotograph that it contains ferritic structure containing some fine pearlite at grain boundaries.

microphotograph that it is essentially a ferritic structure containing some fine pearlite at the grain boundaries.

The base metal in the vicinity of a weld is subjected to a complex thermal cycle in which all temperatures from the melting range of the steel down to room temp. are involved. The metallurgical changes in the HAZ are determined by the thermal history of each portion of the zone and particularly by the rate of cooling. The thermal cycles of welding are relatively short compared to conventional heat treatment cycles. The weld metal and HAZ base metal may contain soft, at most fully hardened or mixed soft and hardened structures. The cooling rates depend mainly on three variables such as the rate of heat input, the base metal temp. before welding and section thickness and joint geometry.

Part of HAZ becomes heated to austenitic condition and transforms to martensite on being cooled repidly. This rapid cooling results in the formation martensite which is harder and more readily formed in steels of higher carbon content. Martensite also forms more readily where alloying elements are present. The existence of the hard and brittle constituent martensite is undesirable as it is a structure which is susceptible to crack formation. Fig. (8) shows the microphotograph of HAZ. It shows fine grain structure consisting of ferrite and possibly other decomposition products of austenite which is not quite resolved at low magnification. Fig. 9 is the microphotograph of welded metal which represents a cast structure with dendrites.



Magnification-300×

Fig. 8. Macrophotograph of the HAZ. It shows fine grain structure consisting of ferrite and possibly other decomposition products of austenite.

Discussions on the test results

The test results so far obtained by this investigation showed that the endurance limit of the welded joint under above mentioned testing conditions is approximately 8.7 Tons/Sq. Inch. (see Fig. 5 S-N Curve).

Magnification-300×

Fig. 9. Microstructure of welded metal. It shows the cast structure with dendrites.

It was observed that the samples mostly broke at the HAZ which is the most vulnerable area. Fatigue in metals starts due to highly localised yielding. In this phenomenon, weak crystal is surrounded by strong crystals. The whole system is such that it always remains elastic at the highest stress occuring during repeated loading. When the cycle is applied, the weak crystal behaviours are more or less as a single crystal and the properties are, therefore, quite different from others in the system. As the deformation continues, the weak crystal begins to deform in opposite direction and is ready to yield. With each cycle, the weak crystal gets strain-hardened and this strain hardening goes on increasing rapidly. At some point in the process, the material becomes so hard that it cracks on a submicroscopic scale. The hardness of the HAZ is more in comparison to base metal as stress relief treatment was not performed. Moreover, residual stresses were introduced due to thermal input of welding in the welded zone as well as its surroundings. This residual stress some times reaches upto about yield stress and it remains at plane at a certain distance of surface and then cyclic load is applied. This stress concentration along with the cyclic load helps to form submicroscopic crack at HAZ. Therefore, in this case, the failure occured in HAZ. Some samples broke from welded joints. This may be due to inherent defects of the welded joints.

CONCLUSION

From test data obtained by this investigation it can be derived that the endurance limit of welded joint of structural steel under the pulsating load condition (tension as well as compression) is approximately 8.7 Tons/ Sq. inch.

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REFERENCES

1. Cazard, R. "Fatigue of metals", Chapman and Hall (1955) London.
2. Gough, H. J., 'The fatigue of metals' Scott, Greenwood and Sons, London (1924).
3. Frost, N. E. and Denton, K., "The fatigue strength of butt welded joints in low alloy structural steels," British Welding Journal, Vol 14, No. 4 (1967) p 161.
4. Matting, A and Neitzel, M. "The influence of weld defects on the fatigue behaviour of welded constructions," British Welding Journal Vol 14, No. 1 (1967).