Influence of Longitudinal Oscillation on Tensile Properties of Medium Carbon Steel Welds of Different Thickness

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Abstract

The effects of specimen thickness on tensile properties of medium carbon steel welds prepared under longitudinal oscillation were investigated. Medium carbon steel workpieces were welded at different frequencies and amplitudes of longitudinal oscillation. Frequencies and amplitudes of oscillations were varied in the range of 0 to 400 Hz and 0 to 40μm, respectively. Specimens were made for tension tests and microstructure examinations from stationary and oscillatory welded workpieces. Test specimens 8mm, 10mm and 12mm thick were tested and yield strength, ultimate tensile strength, percentage of elongation, breaking strength, impact strength and hardness were determined. Metallographic examination of the test specimens was carried out. Yield strength, ultimate tensile strength, breaking strength, improves significantly but percentage of elongation (+5.5%) reduces in oscillatory (longitudinal) prepared welds in comparison to stationary welded test specimens. The maximum increase in tensile properties (yield strength-21%, U.T.S.-26% and breaking strcngth-39%) in oscillatory prepared welds is at 400Hz -5μm and the minimum increase is at 80Hz - 5μm condition. The oscillatory prepared weld grain size in the case of stationary prepared weld was 38 μm. With increase in specimen thickness from 8mn to 12mm there was some change in values of tensile properties for oscillatory prepared welds. The values are significantly more than the values obtained from stationary prepared welds. The increase in values of tensile properties under longitudinal oscillation is attributed to grain refinement, dendrite fragmentation and grain detachment mechanisms.

Key words: Longitudinal oscillation, weld, medium carbon steel and tensile properties.

1. Introduction

Kou and Le [1,2] observed significantly improved weld' structure and properties, reduction in width of heat affected zone, reduction in the extent of melting of the grain boundary in the partially melted zone, and improvement in strength and ductility, due to low frequency arc oscillation of 2014 Aluminium and 5052 Aluminium alloy. Yamamoto et al. [3] vibrated molten puddle. This gave rise to molten Puddle stirring, which resulted in remarkable grain refinement of weld structure of commercially available Al-Mg-alloy base metal and wire. Solidification crack susceptibility of Al – Mg-alloy weld metal also improved due to grain refinement Miclosi et al. [4] found good effect of electromagnetic oscillation upon the characteristics of welds.

They found that the presence of electromagnetic axial pulsation of the electric arc led to smaller penetration and enlarged the width of a weld. This is a favourable effect from the point of view of heat cracking because deep and narrow welds have a higher risk of heat cracking. Sharir et al. [5] investigated the effect of electromagnetic vibration of arc and the influence of current pulses on the microstructure of welded tantalum sheets. It was observed that there is slight improvement in yield stress and tensile stress, but significant improvement in elongation were observed in arc oscillated welds, compared to welds obtained by conventional techniques. Davies and Garland [6] reported the work of several investigators and concluded that are oscillation produces grain refinement and improvement in mechanical properties. Tewari and Shanker [7, 8, 9, 10] experimentally found beneficial effects of weld pool oscillation on mechanical properties and microstructure of welds. They have found increases in yield strength, ultimate tensile strength and breaking strength of oscillatory prepared welds. Tewari [11] has also reported that due to vibration, the grain structure of welds is refined.

In the case of welding under oscillatory conditions, work pieces are held rigidly on the oscillatory table. The table is rigidly coupled to the vibration exciter and the vibration exciter generates oscillations of different frequencies and amplitudes of oscillation with the help of an oscillator/ power amplifier and transmits them to the table and work pieces. Thus, work pieces oscillate at different frequencies and amplitudes of oscillation. Work pieces are arc welded under these oscillatory conditions. Therefore, molten metal generated by melting of an electrode and the base metal which forms the weld metal, solidifies under oscillatory conditions. This paper presents the effect of longitudinal oscillation on tensile properties of welds having different thickness.

2. Experimental Programme

Medium carbon steel workpieces of different thickness (8mm, 10mm and 12mm) were machined on a shaper and an FN 2 universal milling machine. Work-pieces were straightened in a fitting shop. Two machined workpieces were clamped on the oscillatory table of the experimental set-up (Figure 1) The Oscillatory table was rigidly coupled to the exciter. The table slides freely over the two shafts mounted on bearings on the base plate of the set-up. An Oscillator/power amplifier was used to excite the electrodynamic vibrator at different frequencies and amplitudes of oscillations. The frequencies and amplitudes of oscillations were measured with the help of a vibration meter along with a vibration pick-up. The two medium carbon steel work pieces of 400mm×200mm of 8,10 and 12mm thicknesses were clamped with C-clamps on the oscillatory table. These two work pieces were welded with mild steel electrodes (AWS-E 6013) under stationary and oscillatory conditions with a three phase welding transformer. Work pieces were welded in the middle by making a single V-groove by machining.

The frequency range of oscillation was 0-400 Hz at amplitudes of 0µm, 5µm, 10µm, 20µm, 30µm, and 40µm. Voltage and current were maintained in the range of 25-30 volts and 130- 140 amps. Respectively. During experimentation, input energy, arc length, speed of electrode travel and other electrode parameters were kept almost the same. During investigation, the frequency and the amplitudes of longitudinal oscillations were increased from 400Hz to 600Hz and 40µm to 70µm. Deterioration of mechanical properties was obtained, therefore, all experiments were done up to 400Hz frequency and 40µm amplitude of oscillations.

Tensile butt welded test specimens were fabricated from welded workpieces as per Indian Standard IS3600, 1973 specifications. These specimens were machined on a shaper and a milling machine. Sharp corners were smoothed to avoid stress concentration. The central portion was reduced in cross section compared with the end portion to ensure fracture at weldments. The End shape was made to suit the gripping device of the tensile testing machine. A Test specimen was long enough to ensure that necking does not take place near the ends. All surface irregularities were removed in machining the test specimens.

Microstructure study samples (cross section 10mm x l0mm) were cut from welds of plate thickness 8mm, 10mm, and 12mm with a hacksaw. Rough grinding of these specimens was carried out on a belt sander and specimens were kept cool by frequent dipping in water. Rough grinding was followed by fine polishing. For micro-structural studies of these polished specimens, the structural characteristics were made visible by dipping the specimen in an etchant (2% nital solution) for about 10 seconds and later washed with methanol. Etched specimens were used for micro structural studies.

Tensile test of welded (longitudinal) specimens under stationary and oscillatory conditions were done on a 30-ton universal testing machine. Yield strength, ultimate tensile strength, breaking strength and percentage of elongation of the welded test specimens were recorded. A Leitz metallurgical microscope was used to conduct metallographic examination of the test specimens. The specimen surfaces were viewed at the centre of the welds and at extreme ends along X, Y and Z directions and micrographs were taken at 200 magnification. The Linear intercept technique was used for grain size determination from micrographs. The Length parameter is the mean intercept length.

$$L = L_T/PM$$

Where, L = Grain size, microns
L_T = Total test line length, mm
M = Magnification
P = Number of grain boundary intersections

In this study the test line length selected was 50 mm. A 50mm line was drawn on a transparent sheet which was kept over the micrograph and the number of grain boundary intersections were actually counted. This process was repeated 6 times in different directions, on the same photograph to get an exact picture of grain size. The average of the 6 values of L gave the grain size of the specimen.

3. Results and Discussions

Figure 2 shows the effect of frequencies on yield strength. It is evident from the figure that as the frequency increases, yield strength increases and has maximum value at the highest frequency and the lowest amplitude i.e. 400Hz -5µm conditions. The maximum percentage increase in yield strength under longitudinal oscillation at 400Hz -5µm conditions is 21% as compared to yield strengths of stationary welded specimens. Figure 3 illustrates that at 80, 200, 300 and 400Hz frequencies with 5µm and 10 µm amplitudes of oscillation, there is less variation in yield strength with increase in thickness (8mm to12mm), which is logical, as the yield strength is a material property which is independent of thickness. Figure 4 represents the change of ultimate tensile strength with different frequencies. It reveals that longitudinal oscillation bring about an increase in ultimate tensile strength of welds on the order of 26% at 400Hz - 5μm. Small variations in ultimate tensile strength of welds under oscillation as thickness of specimens increases, is observed. Figure 5 and 6 show that the breaking strength of weldment increases by 39% at 400Hz -5μm longitudinal oscillatory conditions with respect to stationary prepared weldment. Figure 7 illustrates that an increase in specimen thickness has less effect on a change in value of the breaking strength for oscillatory prepared test specimens. Figure 2, 4 and 6 further show that lower frequency (80Hz) and high amplitudes (30μm and 40μm) have best results and as the frequency goes up lower amplitude has a better impact on enhancement of the values of yield strength, ultimate tensile strength and breaking strength. However, the percentage of elongation decreases by 5.5% as the frequency increases, which is evident from Figure 8 and 9 shows that there is not much variation in the percentage of elongation with increase in thickness of oscillatory prepared welds.

Microstructure photographs for a stationary weld (Figure l0) has a grain size of 38μm, whereas a longitudinally oscillated weld has finer grains. One to longitudinal oscillation, following mechanisms are operative in the weld pool which brings about refinement in the grain size of a weldment and by there increases the values of yield strength, ultimate tensile strength and breaking strength and reduces the percentage of elongation for oscillatory (longitudinal) prepared welds as compared to stationary prepared welds.

1. In a liquid metal weld firstly epitaxial grain growth starts in normal conditions of welding, but this is interrupted by competitive growth of grains. During the course of molten weld metal solidification, grains tend to grow in a perpendicular direction to the solid/liquid interface as this is the direction of maximum temperature gradient and thus the maximum driving force for solidification. Longitudinal oscillation brings about formation of new grains. These grains are formed in the weld pool because of dendrite fragmentation and grain detachment due to oscillation. Convection of the weld pool takes place due to different driving forces. This causes dendrite tip fragmentation. Dendrite fragments are taken into the bulk weld pool where they work as nuclei for new grains formation. In grain detachment mechanisms, partially melted grains are loosely held together by the liquid films between them and longitudinal oscillation causes these grains to detach themselves from the base metal. If these grains survive in the weld pool then they work as nuclei for new grains formation.

2. Total cooling rate is enhanced due to longitudinal oscillation of the weld pool. Weld pool stirring has a positive effect on the effective value of thermal conductivity of the liquid pool. This increases the heat transfer of the weld pool.

In cases of low frequency and low/high amplitude (80Hz-30μm), as well as high frequency/high amplitude (300Hz-30μm) of longitudinal oscillations, the above grain refinement mechanisms are less effective because grains obtain less refinement (Figure 11 A grain size -28.8μm at 80Hz -10μm. Figure 11B - grain size - 23.6μm at 80 Hz.-30μm, Figure 11C grain size -13.4 μm at 300HZ-30μm), as compared to 400Hz -5μm (Figure 11D) conditions which have a grain size of 6.2μm. Optimum stirring of the weld pool is produced by optimum intensity of oscillation of 400Hz-5μm. This brings about an accelerated rate of dendrite fragmentation and grain detachment and reduces dendrite spacing considerably. This ultimately results in maximum grain size refinement, thereby giving maximum percentage increase in yield strength (21%)

ultimate tensile strength (26%) and breaking strength (39%) as compared to a stationary weld. Faster cooling of the weld pool due to longitudinal oscillations, forms harder phases, which reduces percentage elongation (5.5%) with respect to welds prepared under stationary conditions.

4. Conclusions

The following conclusions may be derived on the basis of experimental results.

1. Yield strength, ultimate tensile strength and breaking strength of the oscillatory (longitudinal) prepared weldments improve significantly and the maximum percentage increase is 21%, 26% and 39%, respectively, in comparison to stationary prepared weldments. This is due to grain refinement mechanisms as discussed under the heading of results and discussion.

2. Percentage of elongation reduces to 5.5% in the case of an oscillatory (longitudinal) welded specimen.

3. Specimen thicknesses have mach less effect on tensile properties.

4. Best results are obtained at 400Hz. -5µm, longitudinal oscillation conditions.

5. References

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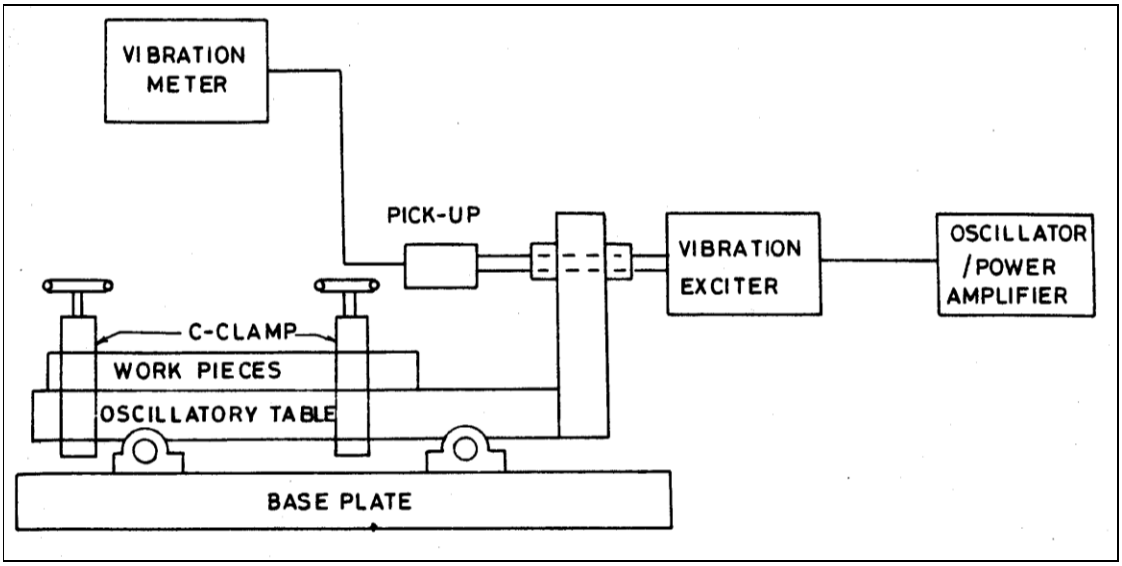

Figure 1. Schematic diagram of the experimental apparatus.

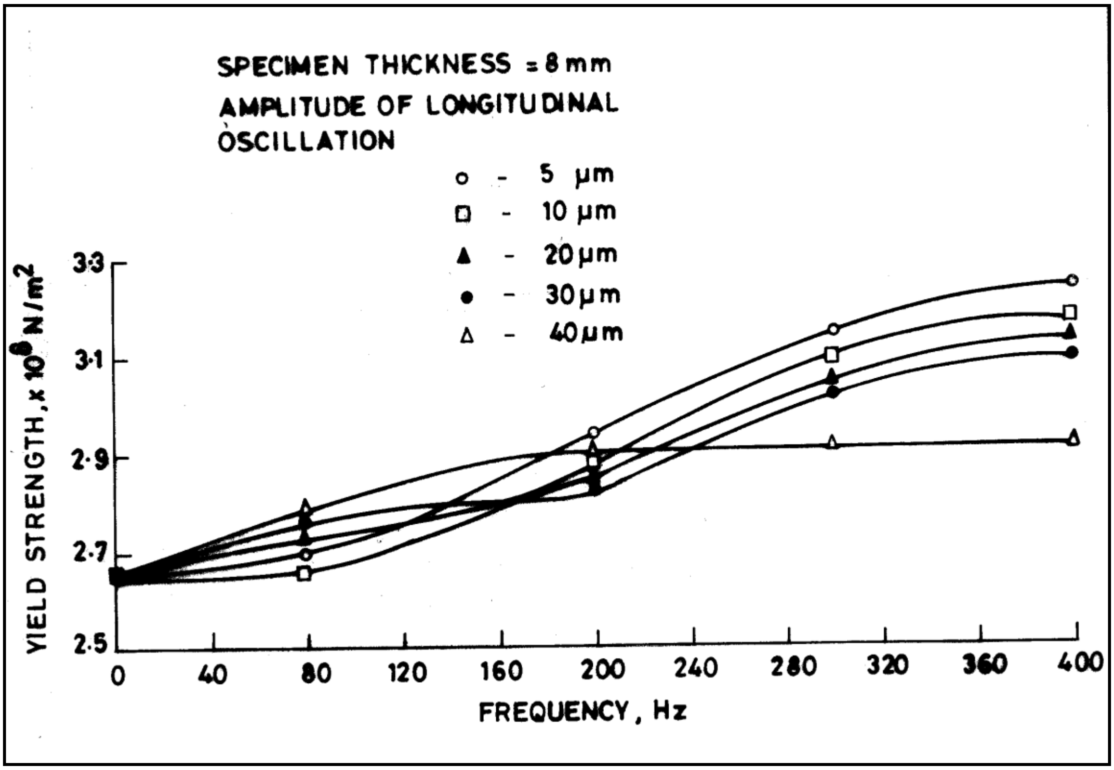

Figure 2. Effect of frequency on yield strength (longitudinal oscillation)

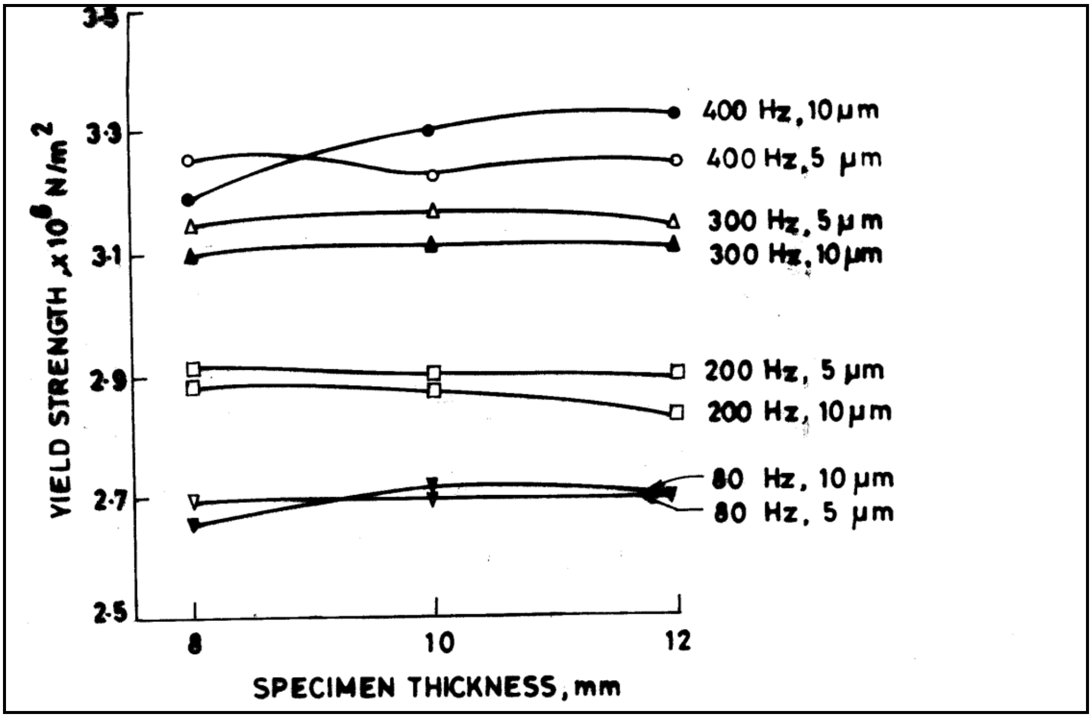

Figure 3. Effect of specimen thickness on yield strength (longitudinal oscillation)

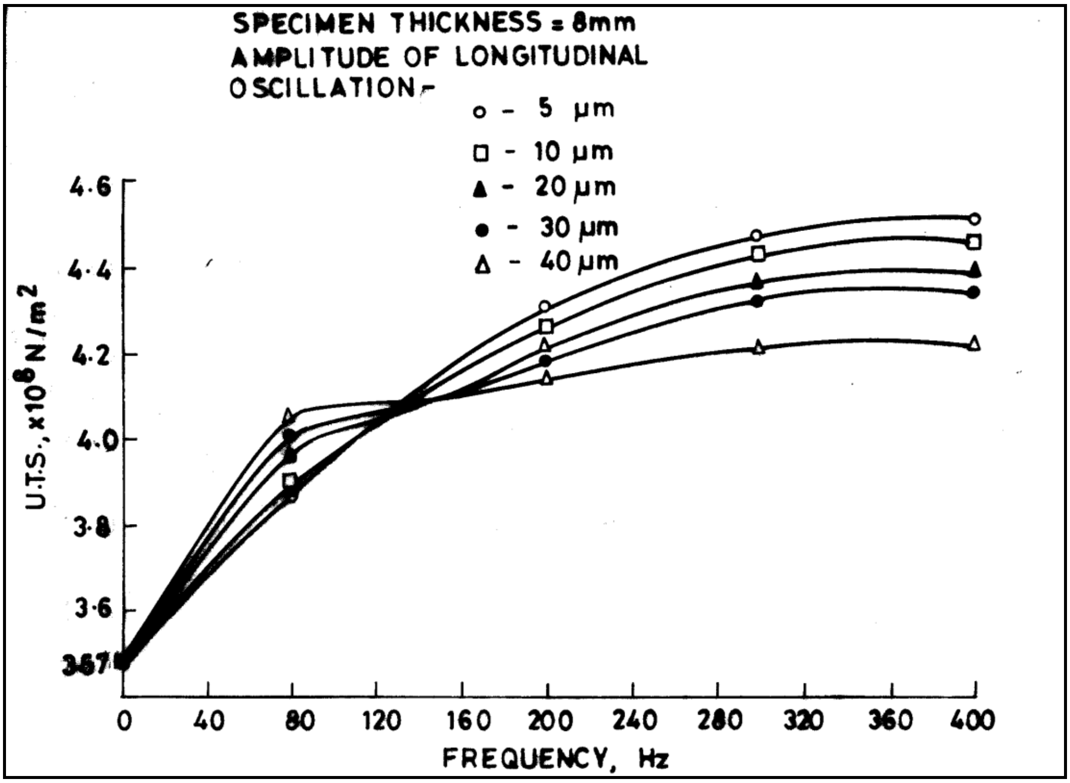

Figure 4. Effect of frequency on ultimate tensile strength (longitudinal oscillation)

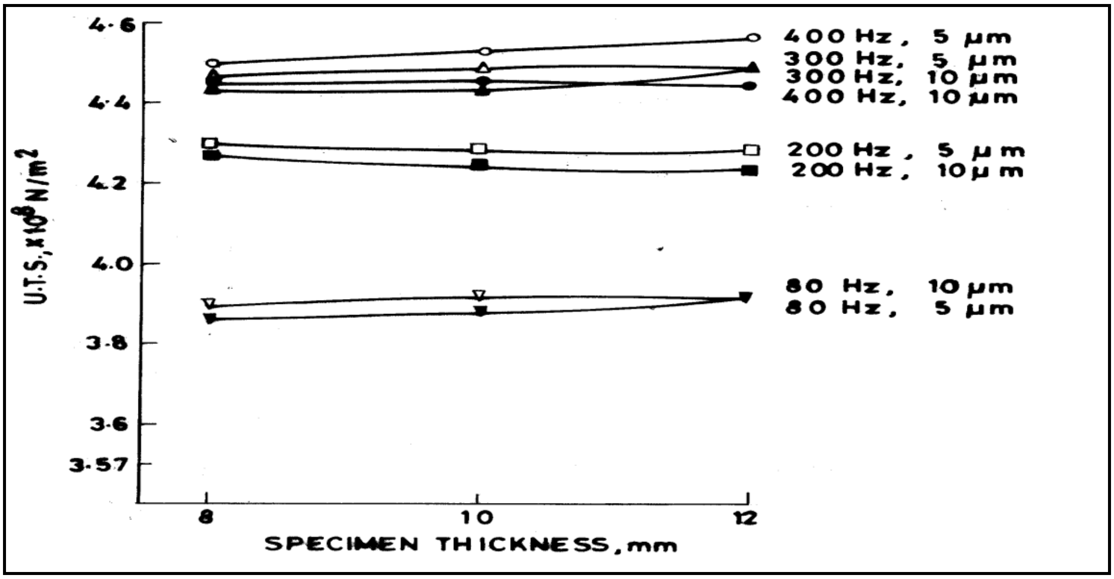

Figure 5. Effect of specimen thickness on ultimate tensile strength (longitudinal oscillation)

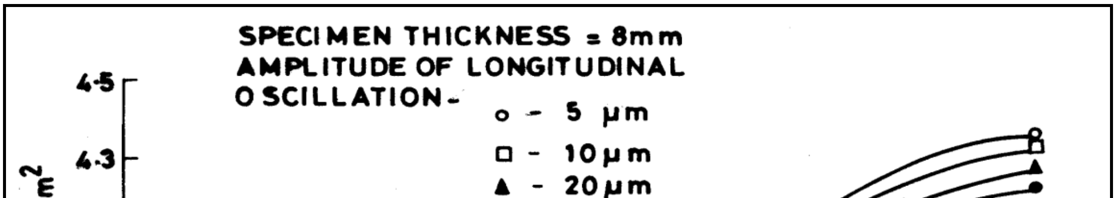

Figure 6. Effect of frequency on breaking strength (longitudinal oscillation)

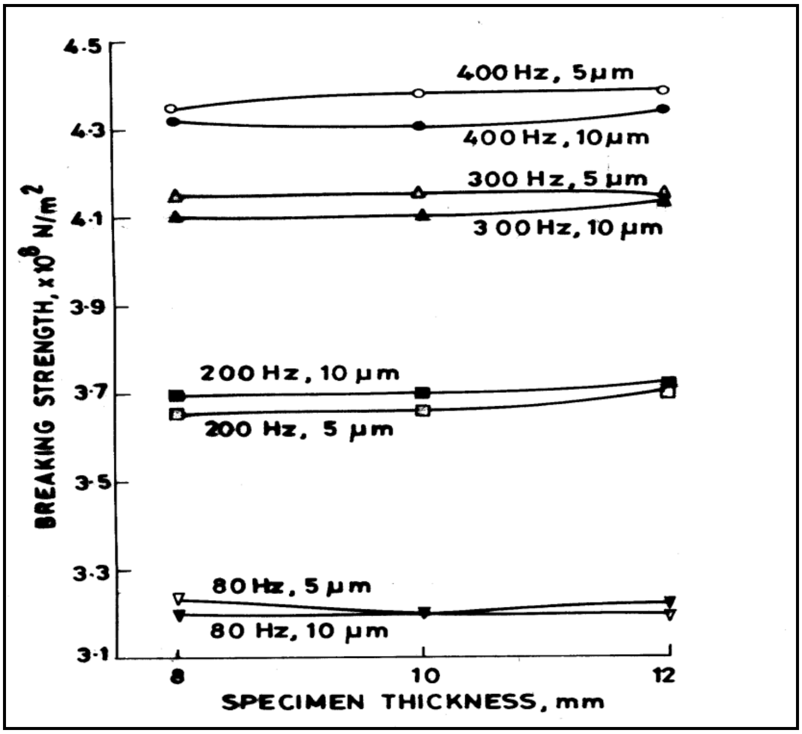

Figure 7. Effect of specimen thickness on breaking strength (longitudinal oscillation)

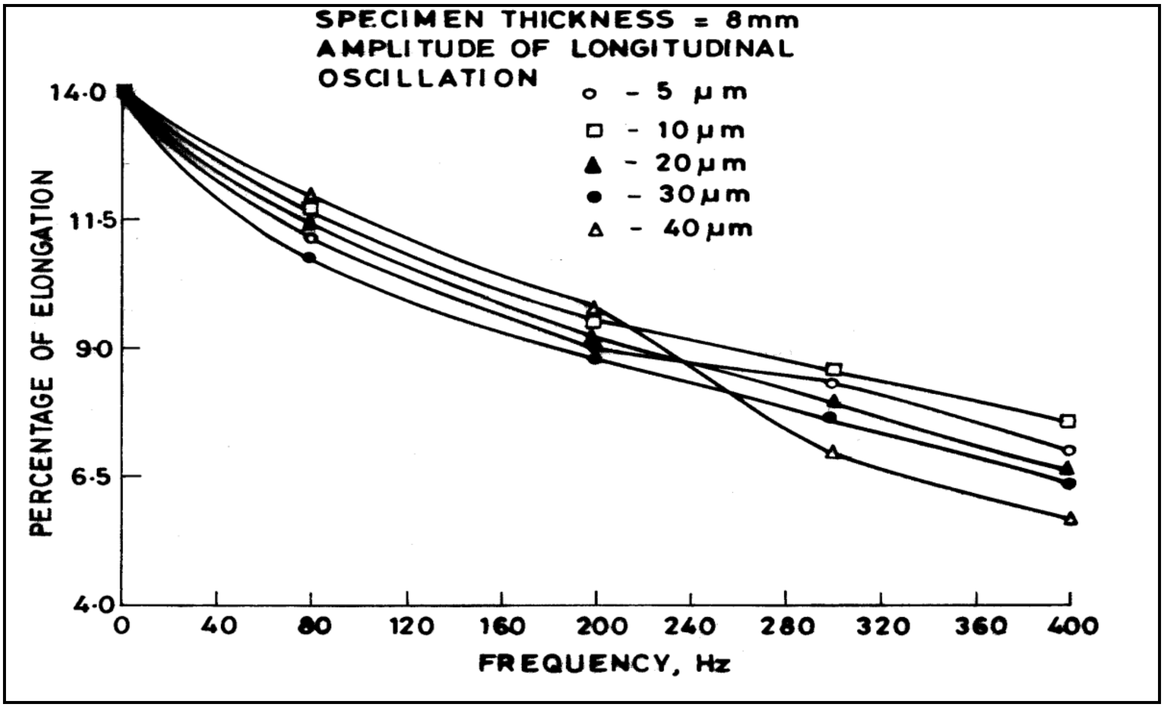

Figure 8. Effect of frequency on percentage of elongation (longitudinal oscillation)

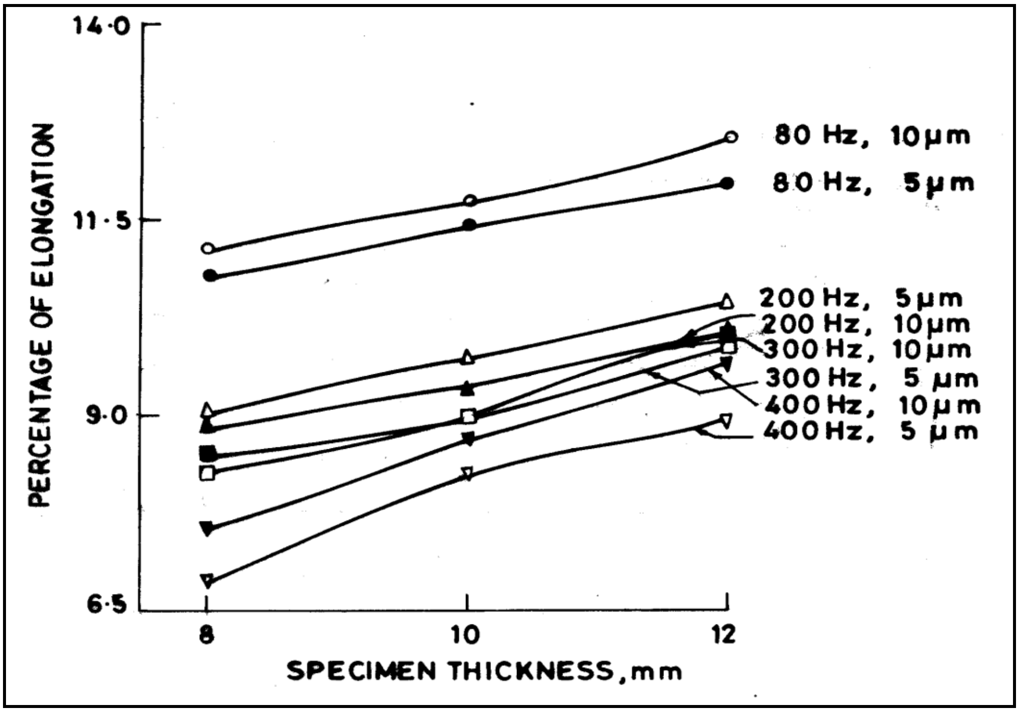

Figure 9. Effect of specimen thickness on percentage of elongation (longitudinal oscillation)

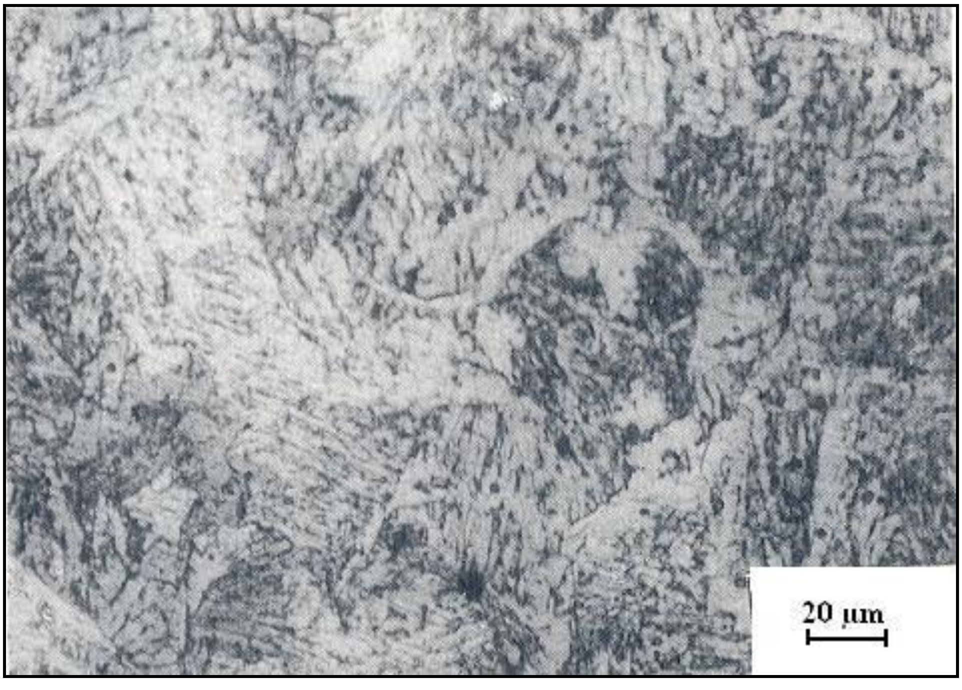

Figure 10. Micrograph of stationary prepared weldment (grain size=38 μm)

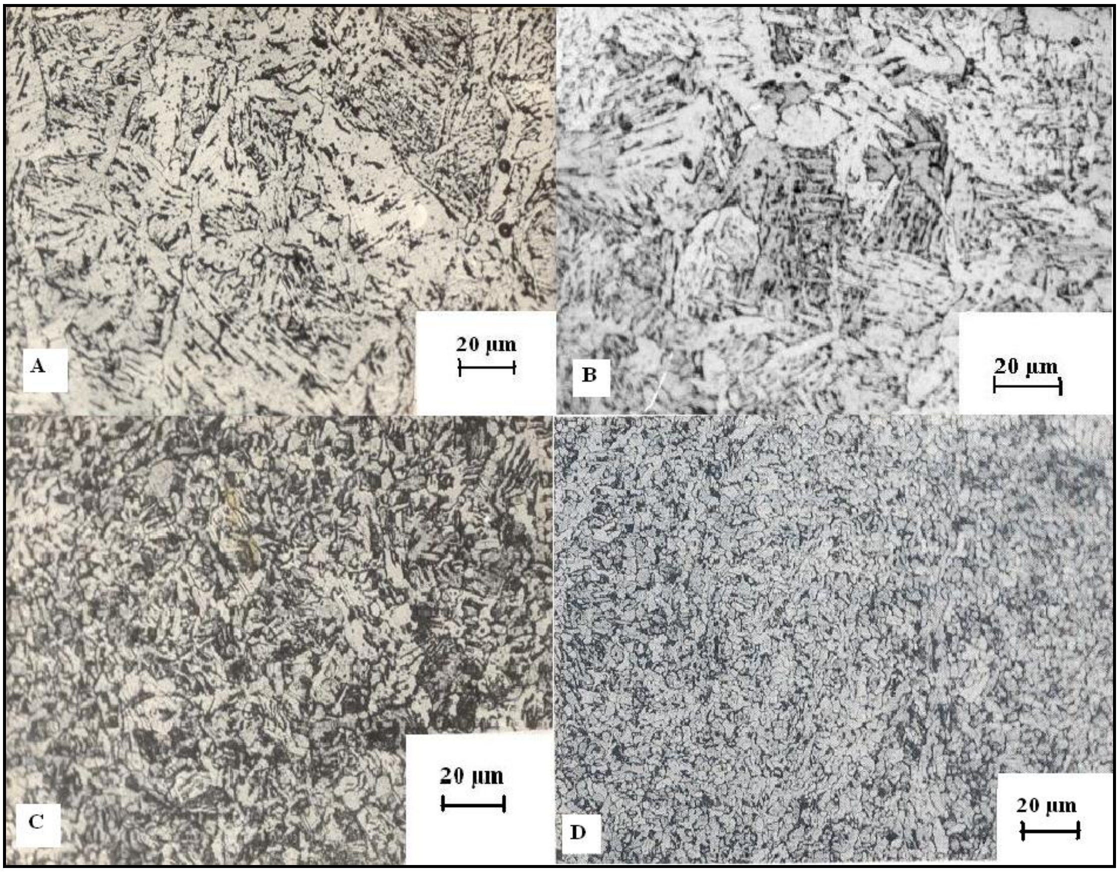

Figure 11. Micrograph of oscillatory (longitudinal) prepared weldment
(A) Grain size=28.8 µm at 80 Hz-10 µm
(B) Grain size=23.6 µm at 80 Hz-30 µm
(C) Grain size=13.4 µm at 300 Hz-30 µm
(D) Grain size=6.2 µm at 400 Hz-5 µm