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# Relaxation mechanism of rotational type in fracture of weld joints for austenic steels

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**Abstract**

Studied is the mesoscale behavior of plastic deformation and fracture of weld joints for austenic steels. Large-scale rotational modes of deformation in heat affected zones are identified with the first stage of formation of band structures; it is related to the "traveling neck" phenomenon in the base metal. The second stage is connected with crack generation and the state of affairs in the heart-affected zone. 

*Keywords:* Mesomechanics; Weld joints; Austentic steels; Heat-affected zone (HAZ); Localized plastic deformation; Mesoscale fragmentation

## 1. Introduction

Weld joint of metal alloys acquires a nonhomogeneous character in the region where the base metal, heat-affected zone (HAZ) and weld material are joined [1–4]. This gives rise to nonuniform distribution of plastic deformation under loading. Localized plastic deformation within the HAZ leads to crack generation and propagation in the material.

Microscopic studies of defects in the crystalline structure for different portions of a weld joint tend to be overly localized. On the other hand, macroscopic consideration may leave out certain details of the material inner structure. Mesomechanics would fill in the gap between events occurring at the micro- and macro-scale level [5]. At the mesoscale level, plastic deformation of the bulk structural element or mesovolume is associated with the translational and rotational mode of deformation. Continuum mechanics can be applied to analyze the deformation of mesovolumes within which microscopic effects prevail. Mesomechanics will be applied to analyze the process of deformation and fracture in the weld joint.

## 2. Description of weld joint and experiment

Specimens with dimensions of 75 mm $\times$ 5 mm $\times$ 1 mm containing cross-shaped weld joint are loaded in tension at a rate of 2 mm/h in an ambient temperature of 293 K. Their surfaces are made from austenic Cr–Ni steel and Cr–Mn high nitrogen steel. Their chemical compositions by percent weight can be found in Tables 1 and 2. Pulse-arc technology in air was used to weld the joints.

The television-optic method [5] is applied to analyze the deformation and fracture of the weld joints at the mesoscale level. This technique

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Table 1
Chemical composition of Cr–Ni steel by percent weight

| Cr | Ni | C | Fe |
|---|---|---|---|
| 18 | 10 | 0.08 | Remainder |

Table 2
Chemical composition of Cr–Mn steel by percent weight

| Cr | Mn | C | N | Fe |
|---|---|---|---|---|
| 17 | 18 | 0.07 | 0.6 | Remainder |

assumes a definite relation between the nonuniform elastic-plastic state of the material and changes that take place on the surface. The measurement equipment includes a microscope, a scanning mechanism, a lighting unit, a TV-camera, a block of specialized interfaces and a computer. The double exposure method was used to record the images of the surface under consideration. The load was applied between the two exposures. Computer processing of the images gave the surface displacement fields. Normal strain $\varepsilon_{xx}$, shear strain $\varepsilon_{xy}$ and rotation $\omega_z$ were calculated using continuous mechanics methods.

## 3. Discussion of results

Displayed in Fig. 1 are the stress and strain relations for the Cr–Ni steel base material and a weld joint specimen. Decrease of strength properties of austenic steel with a weld joint is caused by increase of grain size in the HAZ where softening due to thermal effects occurred as shown in Fig. 2. Anisotropic plastic flow takes place in the HAZ even for 1–2% of plastic strain. Such a plastic flow is developed from the localized shear strain $\varepsilon_{xy}$ and rotational $\omega_z$ given by Fig. 3.

The fluctuating plastic strain and rotation in Fig. 3 form an ordered set of rotational and translational vortices in the HAZ at the mesoscale level. These vortices induce a bending moment on the specimen that generates a series of large scale stress concentrators in the bulk material. They would relax and lead to the formation of isolated macro-bands in the weld joint which are necked and would travel known as the "traveling neck" phenomenon. The direction of the band propagation is independent of the crystallographic properties and is determined by the direction of normal stress. These bands are at 90° to the tensile axis as shown in Fig. 4. They represent the regions of localized plastic flow, within which one portion of the polycrystal has been displaced with reference to another, Fig. 5. This leads to the dissipation of elastic energy and causes a decrease in hardening or the slope $d\sigma/d\varepsilon$ in the weld joint as shown in Fig. 1.

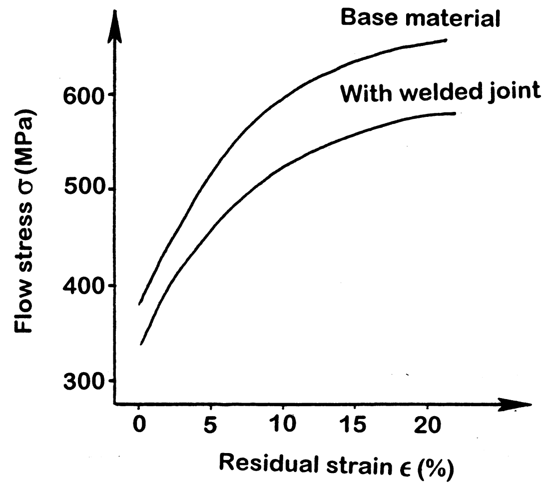


Fig. 1. Dependence of tensile flow stress $\sigma$ on residual strain $\varepsilon$ for polycrystal base material and that with weld joint.

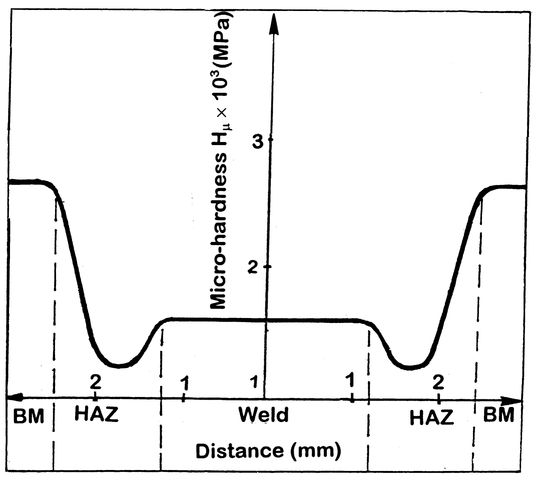


Fig. 2. Distribution of micro-hardness in weld joint.

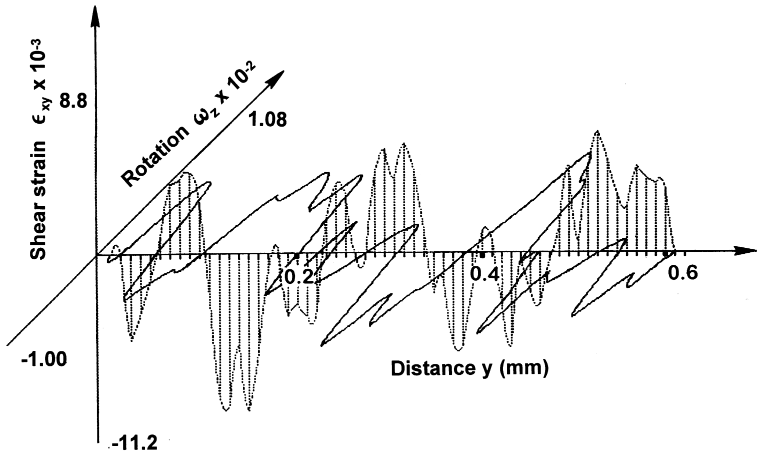


Fig. 3. Distribution of shear strain $\varepsilon_{xy}$ and rotation $\omega_z$ in HAZ normal to specimen axis for 2% strain.

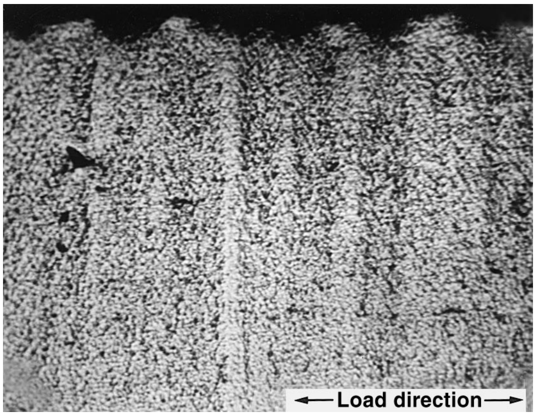


Fig. 4. Macro-band structure magnified 80 times.

When the deformation of the weld joint reaches 18–20% strain, macro-band structure spreads over the bulk material. This is accompanied by an increase of rotation in the HAZ. Mesoscale fragmentation with different directions of shear strain and rotation takes place in the HAZ as illustrated by the displacement field in Fig. 6. Formation of this meso-substructure in HAZ (similar to material fragmentation at the microscopic level [6]) precedes the fracture of weld joints in austenic steels.

Since the nearby meso-fragments are rotated by different degrees, large-scale localized rotation appears in the form of fluctuating plastic deformation (Fig. 7). With increase of the load, the

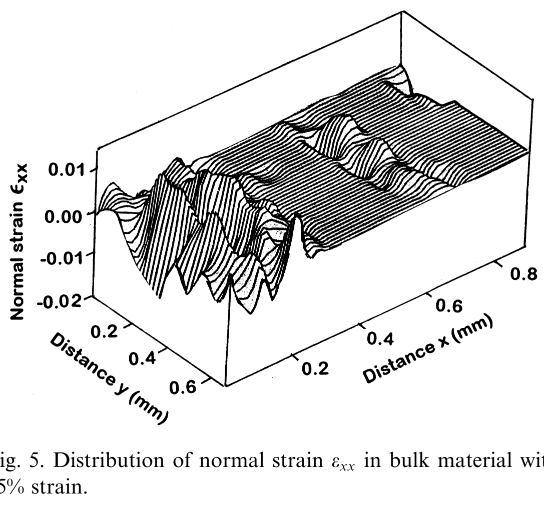


Fig. 5. Distribution of normal strain $\varepsilon_{xx}$ in bulk material with 15% strain.

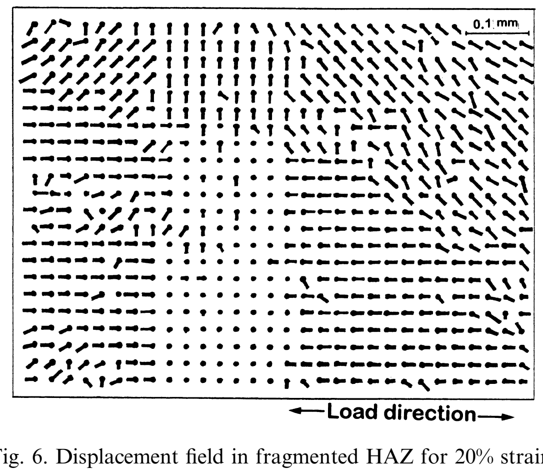


Fig. 6. Displacement field in fragmented HAZ for 20% strain.

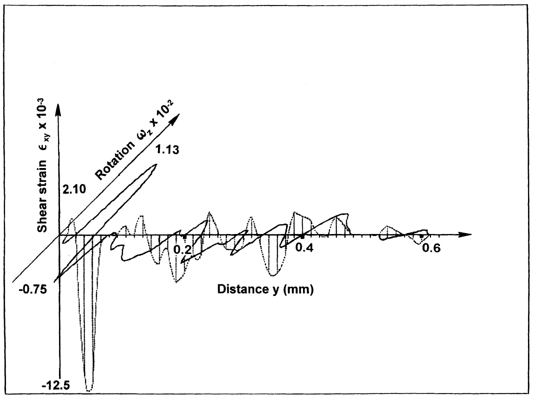


Fig. 7. Shear strain $\varepsilon_{xy}$ and rotation $\omega_z$ in HAZ for 20% strain before fracture.

rotation is permanently increased at the boundary between the HAZ and weld joint. For strain of 22% and 23%, a main crack would be developed that could result in the final fracture of the weld joint.

Fracture behavior of weld joint of austenic Cr–Mn high nitrogen steels is similar to that of Cr–Ni steel discussed above. The same results were also obtained for the deformation and fracture of Cr–Ni steels with electron-beam welded joint. The only difference is in the type of macro-band structures formed in the bulk material. It is caused by smaller width of HAZ in electron-beam weld joints. Less bending moments are available to form the macro-band structures.

## 4. Conclusion

Mesomechanics study revealed new features of deformation and fracture in weld joints. Anisotropic plastic flow in the HAZ and large-scale rotation were found in the weld joints of austenic steels under load. Sharp increase of rotation in the HAZ shows that the formation of band structures tends to deplete plasticity at the mesoscale level. This causes the transition of plastic flow in the HAZ to the macroscopic level. The main crack along the boundary between the HAZ and the joint is thus generated.

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