

# MICROSTRUCTURE OF WELDED JOINTS

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## 1. TYPES OF WELDING PROCESS

Welding is a process of joining smaller pieces and components to build up bigger components. The joining is mostly done by creating a molten pool at the joints. Creation of molten pool is not always desired and thus joining in the solid state is sometimes done. Figure 1 shows the classification of the welding processes. In this paper, discussion will pertain only to microstructures in welded joints made by creating a molten pool which solidifies to give the final joint. The heat input during melting and when the molten pool solidifies giving off the latent heat, and the temperature gradients created due to the heat sink effects by the solid metal surrounding the molten pool affect the microstructure and introduces internal strain in the heat affected zone (HAZ) of the weld joint. There is a large number of books/handbooks which have been published in welding metallurgy in which microstructural aspects have been treated adequately. A few examples are given in References 1-5. The participants are requested to go through them.

## 2. METALLURGICAL PROCESSES IN WELDING

The examples (schematic or otherwise) to be given here pertain to arc welding process which is the most popular method of weld joining.

Figure 2 shows a schematic sketch of the cross section of a butt weld joint with single-run weld deposit. Figure 3 shows the same for a multirun weld deposit. The different zones in Figure 2 are : (i) Solidified zone from molten states having columnar grains, (ii) HAZ (black region), (iii) original (parent) metal region. In Figure 3, the shape of the contour of the weld/metal boundary has changed because of multi pass nature of the weld joint. Also, grain refinements have taken place in the weld deposits due to heat input given during the preceding weld passes.

Figures 2 and 3 give only simplified representations of the microstructural states in weld joints. The actual microstructural states may not have clear cut demarcation lines. Apart from the heat input during the succeeding weld passes, preheating and post weld heating also would affect the microstructures. Complexities in the microstructures would again arise in alloy systems in which precipitations of secondary phases take place at various temperature regions and at various rates of cooling and heating. Figure 4 shows the schematic section across a butt weld joint between a cold worked parent metal at one end and annealed parent metal at the other end.

Figure 5 compares the differences in the microstructures in the HAZ of a metal which does not undergo phase transformation in the solid state (upper figure) and in a metal in which there is a phase transformation in the solid state.

Readers are requested to go through the accompanying papers being presented in this course (Refs. 6-11) to understand the phase transformation behaviour under various conditions.

### **3. MICROSTRUCTURAL FEATURES IN SOLIDIFIED MOLTEN ZONE**

Information on the factors that control the microstructure in a cast product is given in an accompanying paper [Ref. 9]. Similar factors would also affect the microstructure in the solidified molten zone. The molten pool is created in a region flanked by the solid parent metals. The microstructure would then consist of dendrites. The morphology of the dendrite arms and the spacing between them would depend on the cooling controlled by the heat sink effects provided by the solid mass of the already deposited weld pass and the parent metal. Complexity of the microstructure in this zone can be understood from the books on solidification of metals and alloys [Ref. 12,13].

In a system with no phase transformation in the solid state, therefore the solidified molten zone is essentially a single phase with segregations of elements between the dendrite arms and the inter dendrite regions which solidify later than the dendrite arms. In those systems where phase transformations takes place in the solid state, the microstructure either in the dendrite arms or in the space between them would be determined by the phase transformation. Figure 6 shows the microstructure in the weld pool of a low alloy steel.

### **4. MICROSTRUCTURE OF HEAT AFFECTED ZONE**

The heat affected zone more commonly known in its abbreviated term HAZ is the region with the weldmetal boundary at one end and the parent metal microstructure unaffected by welding on the other. Typical microstructural features possible in the types of alloy systems have been indicated in Figures 2 to 5. The factors which play important roles in altering the microstructures are temperature gradient and physical constraints. The effect of temperature is manifested by (i) grain growth (ii) phase transformation for example change over from ferrite to austenite in many of the alloy steels followed by retransformation of the austenite during cooling to martensite/bainite/ferrite. The temperature gradient is introduced in a weld joint by the heat sink effect of the surrounding "cold" parent metal. The degree of the temperature gradient is deliberately reduced by pre-heating in alloy steels in which the tendency of the formation of martensite or bainite is prominent [Fig. 7]. In such cases, the microstructure would consist of tempered martensite and tempered bainite. Temperature distribution in the HAZ area during weld deposit and during cooling determines the microstructure. Figure 8 in the HAZ of a 304 stainless steel weld joint. The figure shows the grain growth region adjoining the weld/parent metal boundary. Away from

the boundary, there is the zone of sensitisation (black grain boundaries). This is shown more clearly in Fig. 9. Sensitisation is a phenomenon of precipitation of carbides at the grain boundaries that takes place in a temperature range of 550-750°C. As can be seen in Figure 10 due to the temperature distribution characteristics that are present in the HAZ, the sensitisation (also known as 'weld decay') takes place in a narrow spatial range in the HAZ.

Figure 8-10 signify that the microstructures in the HAZ depend on the temperature distributions in the HAZ. Importantly again, the microstructure depends on the corresponding phase diagram of the alloy system. Figure 11 highlights this point for a precipitation hardening alloy such as duralumin. To understand the various microstructure possible in a precipitation hardenable alloy can be found in Ref. 7 and 10. Figure 12 shows the relationship of the phase diagram of Fe-C system and how the temperature distribution would affect the microstructure.

## CONCLUSIONS

This paper has discussed some of the important factors like temperature distribution, phase diagram, number of passes etc. on the microstructure in the weld metal and the heat affected zone of a weld joint.

## REFERENCES

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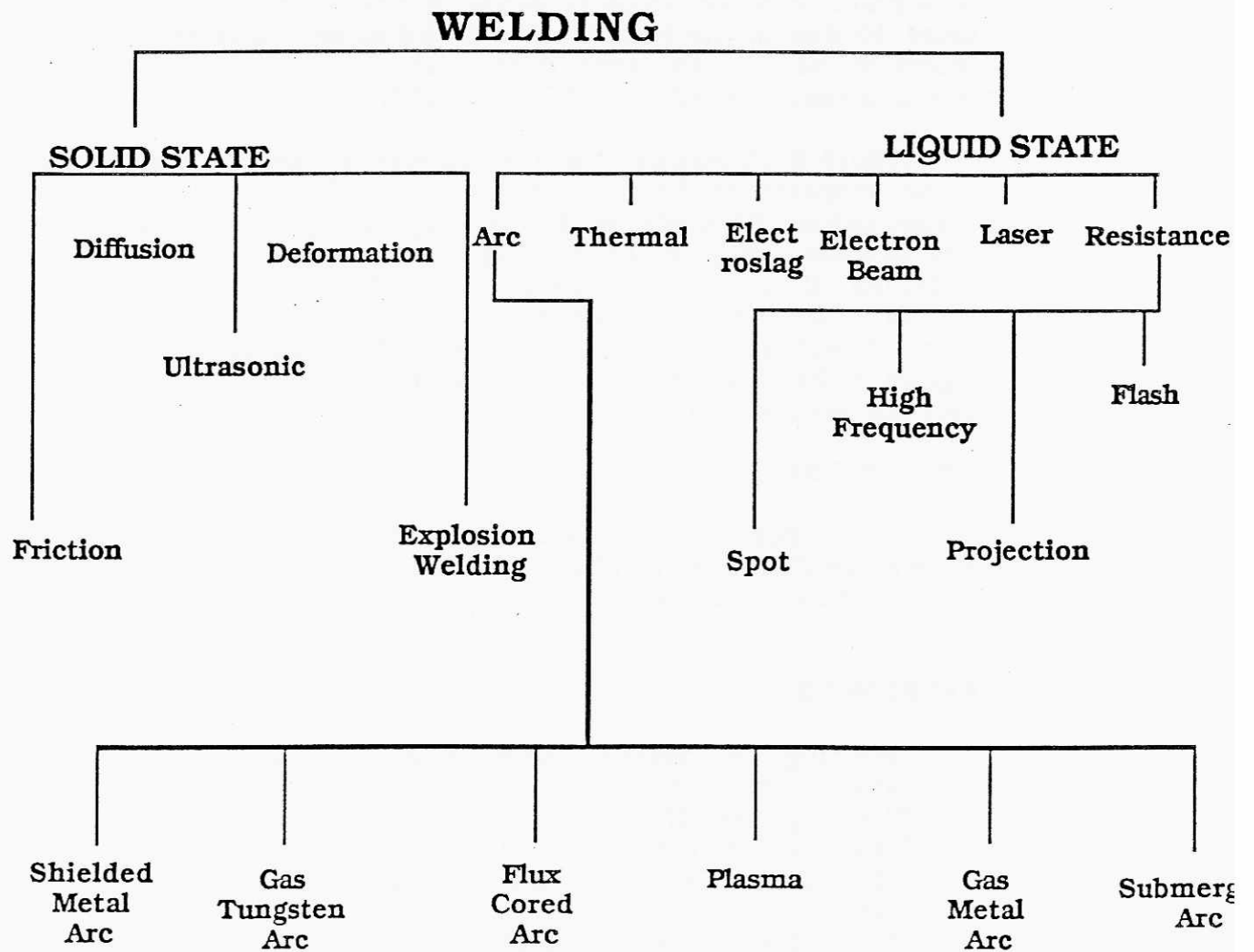


Fig.1 Various Welding Processes

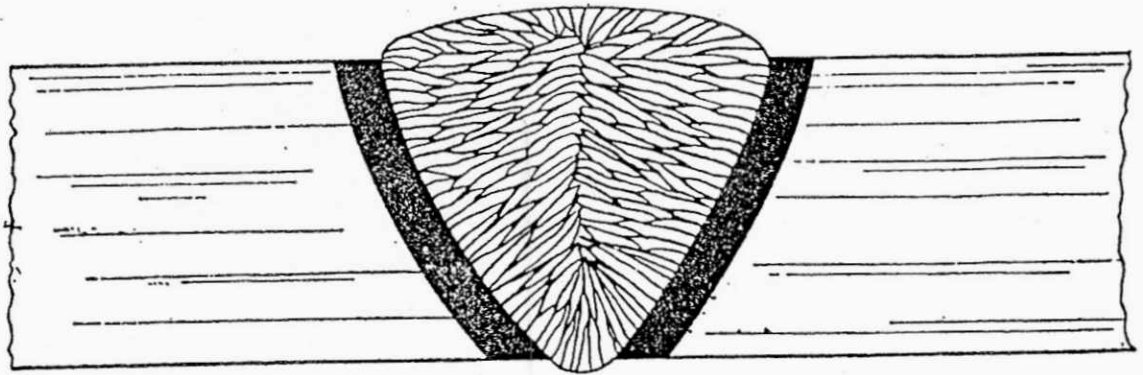


Fig.2. The cross-section of a single-run weld deposit

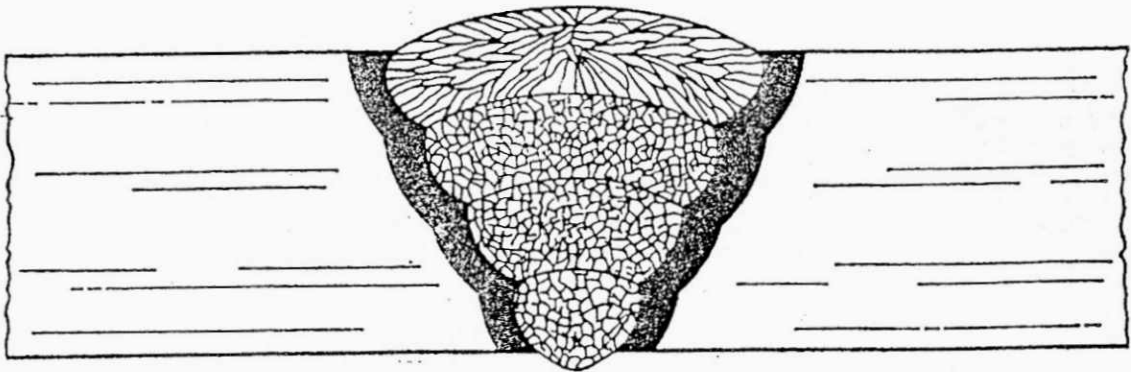


Fig.3. The cross-section of a Multi-Run Weld Deposit

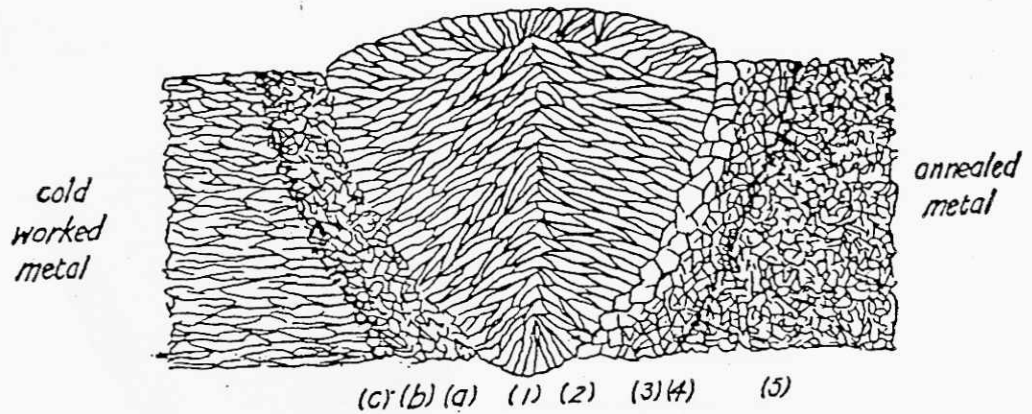


Fig.4. Cross-section across a Butt Weld Joint between a cold Worked Parent Metal at one end and Annealed Parent Metal at the other end, (1) Columnar Grains (2) over heated zone-grain growth (3) Refining zone-complete recrystallisation (4) Transition zone-partial recrystallisation (5) Parent metal- unaffected annealed structure (a) Refining zone-complete recrystallisation, (b) Transition zone-partial recrystallisation, (c) Parent metal- unaffected cold worked metal

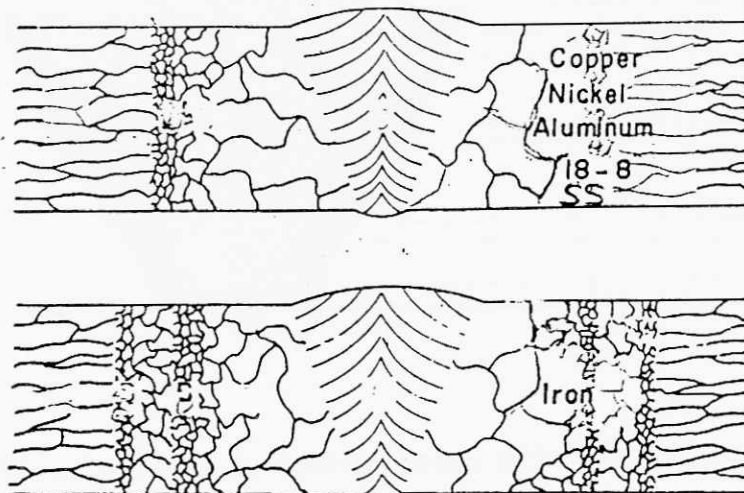


Fig.5. Difference in the Microstructure in the HAZ in the Butt Weld Joints in Metal undergoing Phase Transformation in the solid state or otherwise.

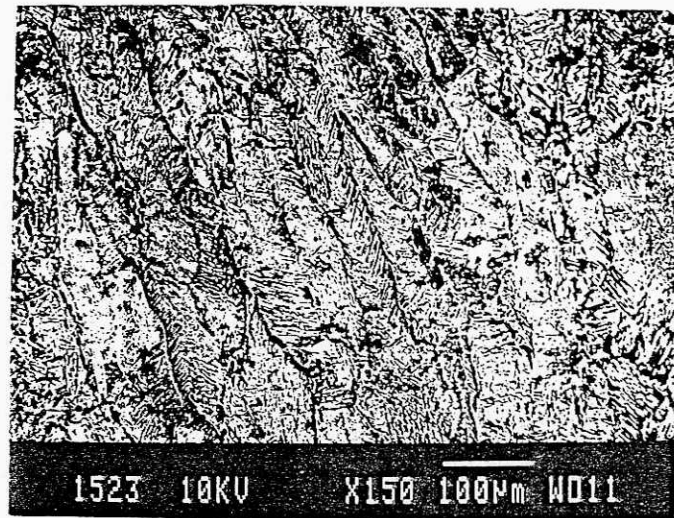


Fig.6. Dendritic pattern in the weldment of a 15CDV6 low alloy steel.

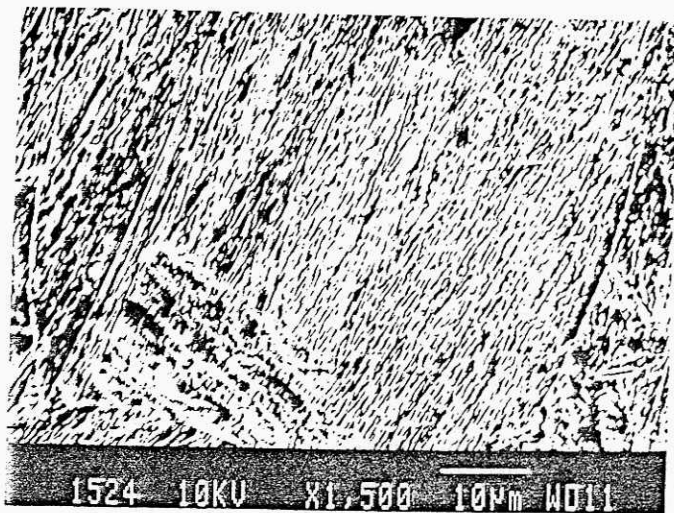


Fig.7. The Bainitic microstructure in the HAZ of the weld joint of a 15CDV6 low alloy steel.



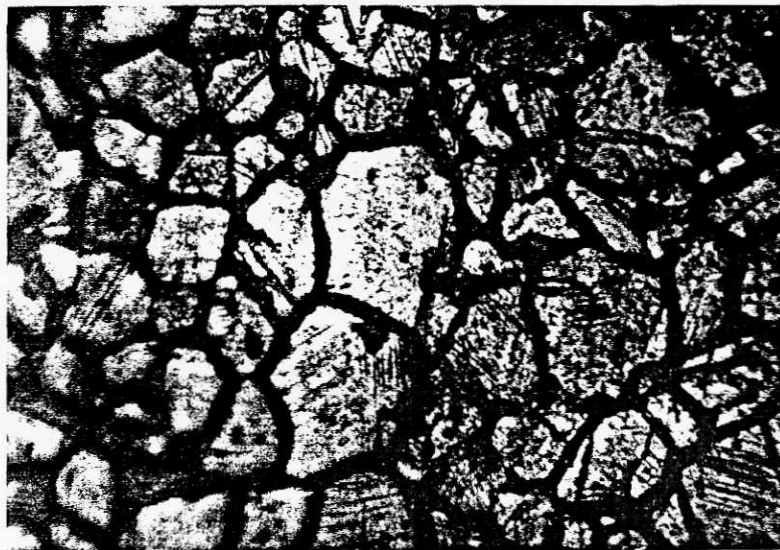


Fig.9. Sensitisation in the HAZ of weld joint of 304 SS away from the weldmetal/HAZ boundary.

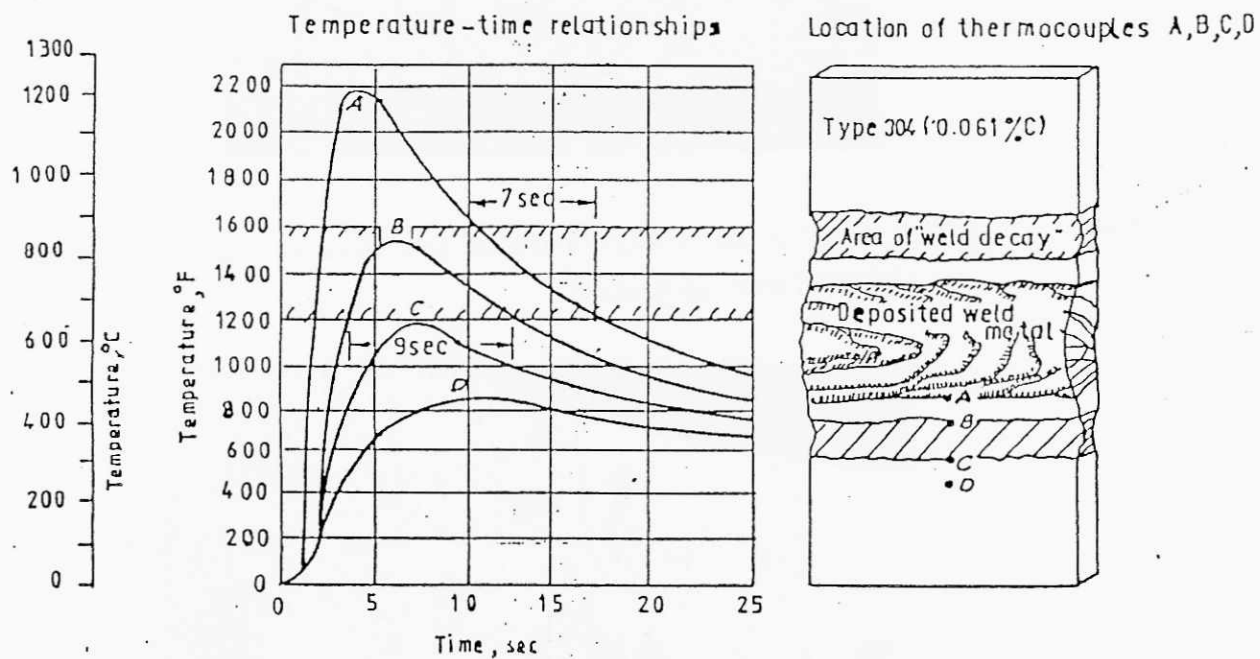


Fig.10. Weld decay by sensitisation in AISI 304 stainless steel.



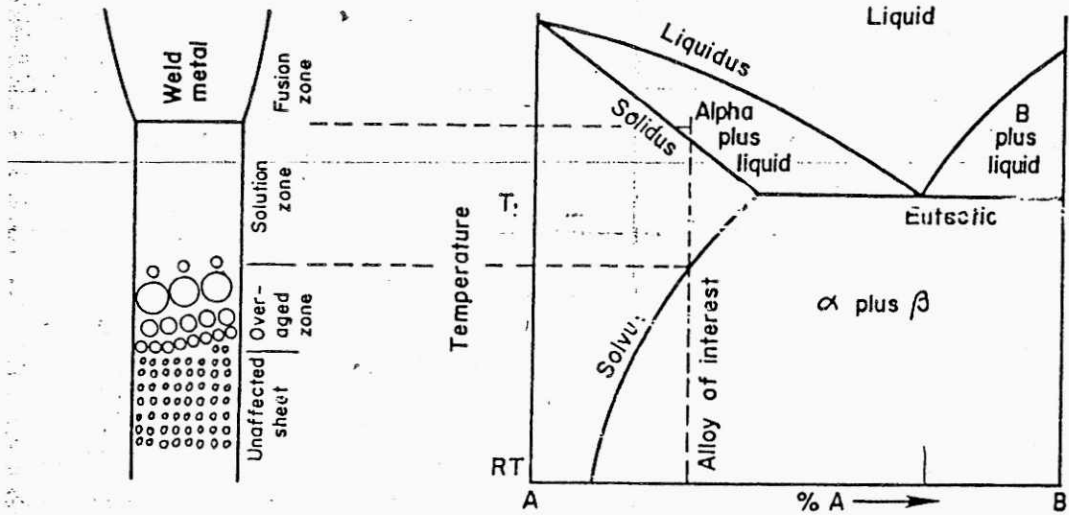


Fig.11. Phase diagram of a precipitation hardenable alloy system and its relationship with the microstructure at the different regions of HAZ.

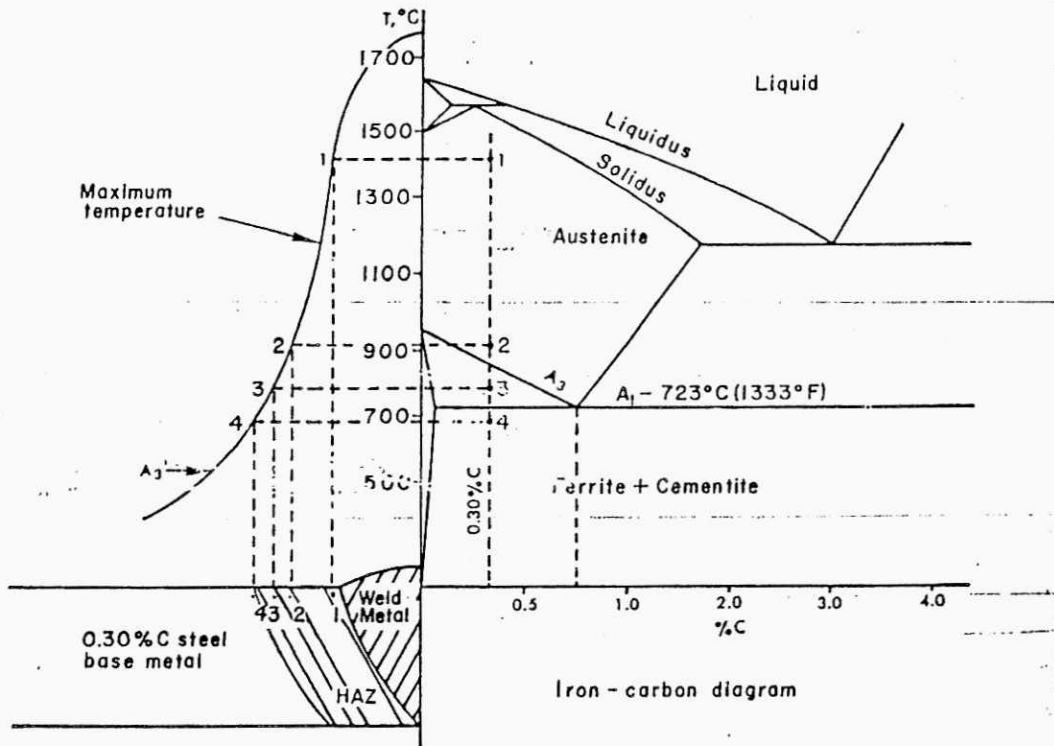


Fig.12. A portion of the phase diagram of Fe-C system and its relationship with the microstructures of the different regions of the HAZ.