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FORMATION OF ACICULAR FERRITE ON NON-METALLIC INCLUSION IN LOW-ALLOY WELDED JOINTS

Radica M. Prokić-Cvetković, Andjelka J. Milosavljević,
Aleksandar S. Sedmak, Olivera D. Popović, Sanja J. Petronić
Faculty of Mechanical Engineering, University of Belgrade
Kraljice Marije 16, Belgrade
Serbia & Montenegro

ABSTRACT
Compared to other highly organized morphologies of feritte, microstructure of acicular ferrite could be described as haotic. Acicular ferrite is sometimes considered to be intragranularly nucleated Widmanstatten ferrite. For others, it is intragranularly nucleated bainite. However, the plates of acicular ferrite nucleate heterogeneosly on small non-metallic inclusions and radiate in many different direction from these point nucleation sites. This paper describes different types of nucleation of acicular ferrite on non-metallic inclusion.
Keywords: inclusion, nucleation, acicular ferrite

1. INTRODUCTION
Today, it is accepted in welding metallurgy that the morphology characterized by interwoven needles/plates,extending in several directions, that are generally nucleated intargranularly (inside grains) on inclusions, is termed as acicular ferrite. Later, it is established that such a structure can be formed also in low carbon microalloyed steels containing added inoculants, and it is demonstrated that acicular ferrite can be formed also in medium carbon microalloyed steel [1,2]. Experiments have shown that in fact acicular ferrite is identical to bainite, but their morphologies differ in that acicular ferrite nucleates intergranularly on inclusions inside large γ grains, while bainite initially nucleates on γ-γ grain surfaces and grows by repeated forming of subunits until bundled morphology is created [3]. Nucleation develops heterogeneously at nonmetallic inclusions existing in steel. Development of nucleation requires sliding of contact surfaces between the nucleus and matrix. Dislocation pile-ap in austenit in the vicinity of inclusion assures required sequences that develop the corresponding nuclei [4,5]. Acicular ferrite growth is non-diffusional [6].

2. MECHANISM OF NUCLEATION AND THE ROLE OF INCLUSIONS
Opinions on mechanisms of acicular ferrite formation are different. According to one notion, acicular ferrite is intragranularly nucleated Widmanstätten ferrite, or intragranularly nucleated bainite, accoarding to others[1,2,7].
Latest research of C-Mn-Ni welds has shown that the first group of acicular ferrite needles had nucleated at inclusions, confirming that nonmetallic inclusions represent initial nucleation sites for acicular ferrite. The scheme in Figure 1 presents different types of acicular ferrite nucleation and induced nucleation [8,9]. It is clear from Figure 1 that interrelation between ferrite needles and inclusions changes and depends on growth orientation of the nucleated embryo. Acicular ferrite nucleation and longitudinal directions of growth are indicated by arrows in Figure 1a and 1b. Nucleation and growth of this AF type creates two morphologies, „engulfed“ nucleus inclusion (Figure 1a and 2a), or long ferrite needle contacting the inclusion on one side (Figure 1b and 2b). The

first morphology is tipical for smaller inclusions and the later for larger ones. In Figure 1c and 2c „star-like“ nucleation is presented with inclusion located in the centre of ferrite star, i.e. ferrite needles emanate from the inclusion in multiple directions. This nucleation tipe is also typical for larger inclusions [8,9]. Formation of acicular ferrite laths at inclusion can induce autocatalytic reaction, so the number of active inclusions does not agree to the number of acicular ferrite plates [6,8].

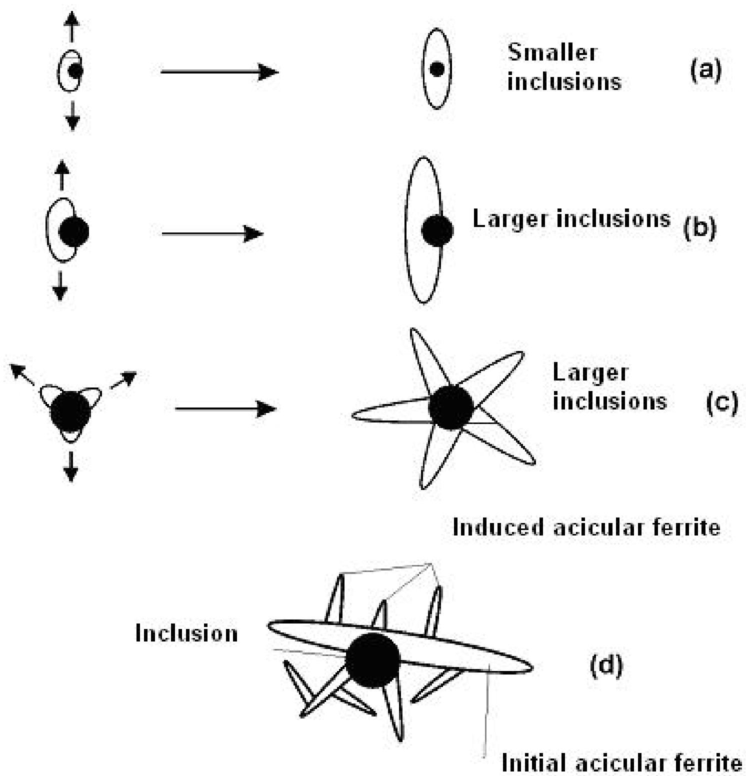

Figure 1. Model of nucleation and orientation growth of acicular ferrite: a), b) parallel; c) perpendicular to inclusion surface; d) acicular ferrite nucleation induced at existing ferrite laths [8,9].

Acicular ferrite nucleation affected by inclusion is followed by the so-called induced nucleation. Induced ferrite laths normally nucleate from existing acicular ferrite that has formed by nucleation on inclusions. These induced ferrite needles grow at large angles to initial ferrite needles which they nucleated from, and are smaller in size (Figur 1d and 2d) [8,9]. Acicular ferrite can also induce by nucleation on grain boundaries of proeutectoid ferrite and austenite, but this type of nucleation is very rare in comparasion to the intragranular nucleation type, Figure 3[9].

Nucleation inclusions in welds with mean (200-300 ppm) and low (15-30 ppm) oxygen concentrations are similar in size, but the most active inclusions are 0,3-0,9 μm in diameter (particulary 0,56 μm) [8]. This agrees with results of other authors [10,11] who discovered that inclusions >0,2 μm in diameter are most important for nucleation of acicular ferrite. The chemical composition of active inclusions, on which acicular ferrite nucleates, varies. All inclusion types, such as TiO_2, Al_2O_3, SiO_2, MnO-SiO_2, TiO(or Al_2O_3)-MnO-SiO_2, MnS (and MnS surface coating),(MnCu)S (and its coating) [8,9],TiN [6,12], MnOxAl_2O_3 [9,12], MnOxTiO_2 [5] can nucleate acicular ferrite in the initial transformation stage. Grong claims [12] that acicular ferrite nucleates at only 15% of the total inclusions.

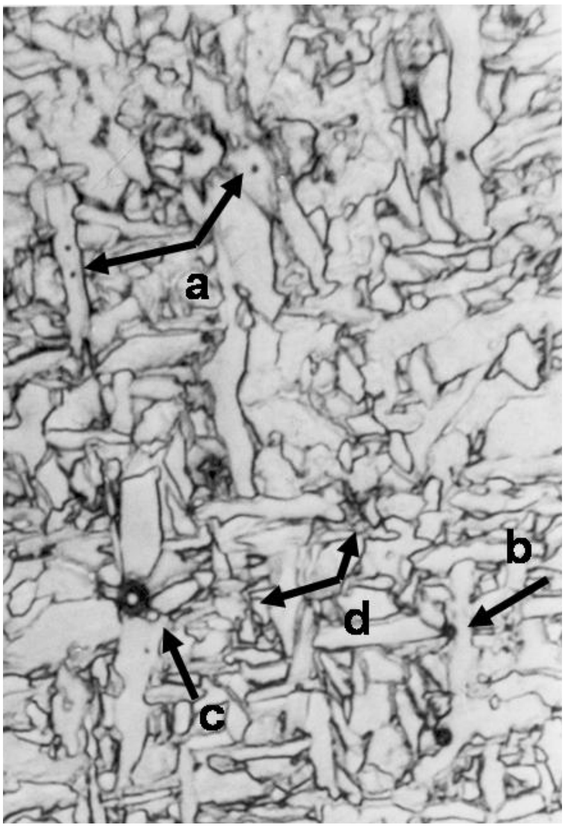

Figure 2. Nucleation and orientation growth of acicular ferrite: a), b) parallel; c) perpendicular to inclusion surface; d) acicular ferrite nucleation induced at existing ferrite laths

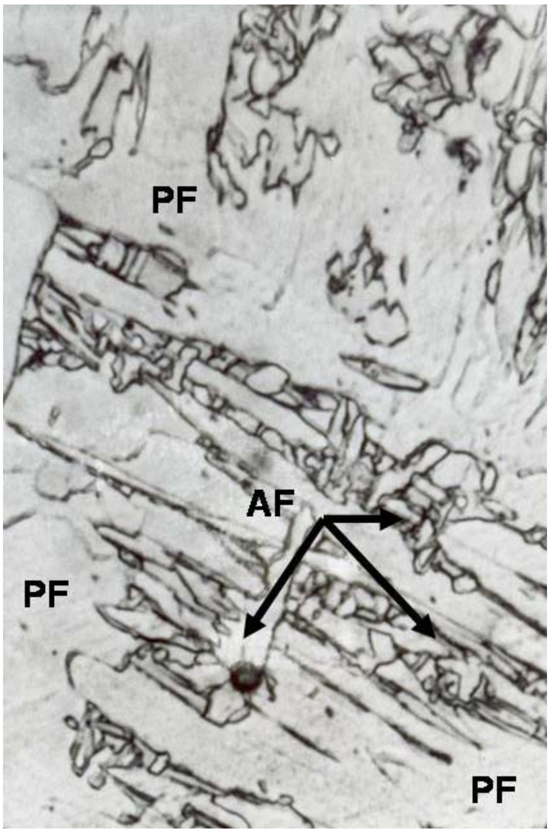

Figure 3. Nucleation of acicular ferrite on grain boundaries of proeutectoid ferrite and austenite

Larger spherical non-metallic inclusions are more effective for heterogeneous nucleation. An embryo which forms in contact with the surface will have a smaller curvature and a corresponding smaller surface-to-volume ratio when the inclusion is large[13]. A flat austenite grain surface is therefore expected to be a more potent heterogeneous nucleation site than a spherical inclusion. Furthermore, the energy of the interface between the ferrite and the inclusion is likely to be larger relative to the case when ferrite nucleates on austenite grain surfaces. It follows that the activation energy for nucleation on an inclusion, relative to that for nucleation on an austenite grain surface should vary as illustrated in Fig. 4.

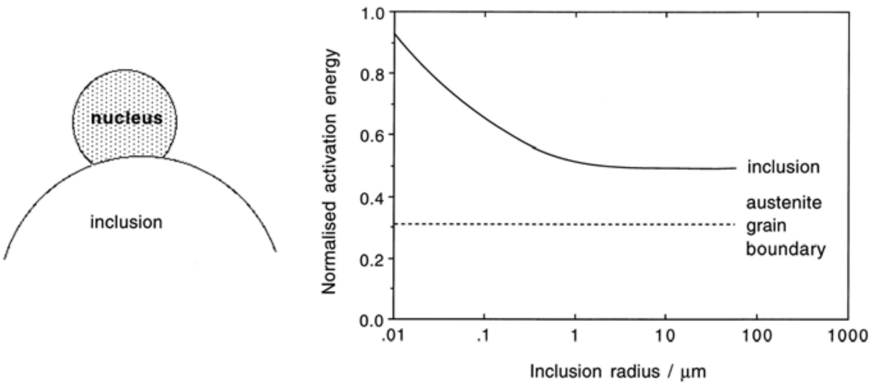

Figure 4. The formation of a truncated spherical nucleus on a spherical inclusion [13]

In figures 2 and 3 are showned weld metal microstructures of steel microalloyed with Ti, Nb and V. The chemical composition is: 0,074%C, 0,54%Si, 1,37%Mn, 0,01%Al, 0,013%Nb, 0,006%Ti, 0,82%Ni. The larger inclusions are oval shaped and complex type, such as $MnOxAl_2O_3$ or SiO_2, and they are nucleus for MnS coating. Pure MnS or Al_2O_3 are rare.
Also is noticed great number of smaller inclusion, and it is presumed that they are carbides, carbonitrides and oxides. In areas around inclusions have been noticed single or cluster porosity [9].

3. CONCLUSION

Considering performed tests the following is concluded:

1. The presence of inclusions is very important for the formation and growth of acicular ferrite in the weld metal of microalloyed steel.
2. It is showned that inclusions, such as MnS and MnS surface coating, (MnCu)S and its coating and $MnOxAl_2O_3$, can nucleate acicular ferrite in the initial transformation stage.
3. "Star-like" nucleation is typical for larger inclusions, while for smaller inclusions is typical that needle contacting the inclusion on one side or captive it.

4. REFERENCES

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