DOI: http://dx.doi.org/10.15407/tpwj2019.01.05

INFLUENCE OF MAGNETIC FIELD ON CRYSTALLIZATION OF WELDS IN ARC WELDING

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A review of publications on metallurgical and casting industry showed that when analyzing the properties of liquid metals and alloys, many authors proceed from the concepts of their cluster structure. Cluster structure of liquid is a hypothesis, but it is confirmed by studies of diffraction of X-rays, electrons and neutrons, reflected from its surface. The work considers the existing concepts of a cluster being a crystal-like concentration of atoms. Around the clusters a softening zone exists, which consists of disordered atoms. Its volume does not exceed 3–5 % and this provides the fluidity of many melts. The authors of publications have succeeded in explaining the forming structure of ingots, based on the cluster mechanism of the process of crystallization of liquid metals and alloys. The authors of this work suggested that the overheated liquid metal in the head part of the pool, which has smaller clusters, moves under the action of magnetic fields to its tail part, and provides a refinement of the primary structure of the weld metal. 20 Ref., 1 Figure.

Keywords: *welding, weld pool, magnetic field, cluster, weld structure, crystallization*

Application of controlling impacts of longitudinal magnetic fields (LMF), or transverse magnetic fields (TMF) in arc welding increases the process efficiency, refines weld structure, and improves welded item performance [1–3]. In [4] it is shown that there exist many hypotheses about the mechanism of weld structure refinement in welding with controlling magnetic fields (MF). Refinement of structural components of weld metal in welding with MF impact, probably, occurs at the stage of their initial crystallization. Known works on the mechanism of metal crystallization during its solidification pertain to casting processes, or to producing superpure single-crystals [5, 6]. Conditions of metal crystallization in the weld pool are known [7, 8] to differ from those described in [5, 6]. It should be also noted that in works [5, 6] and [7, 8] the process of melt crystallization is presented as that of melt atoms bonding with the solid substrate. In all the known works, brief review of which is given in [4], the process of crystallization of various metals and alloys is considered proceeding from the concepts described in [5–8]. Mechanism of crystal growth is represented as bonding of substance atoms from the melt to the solid phase (substrate), i.e. as a diffusion process. Here, the crystallization process is treated as a periodical one, with stopping at release of latent heat of crystallization. A thin solid-liquid interlayer forms on the boundary of the solidifying pool metal with the liquid metal, where diffusion processes (movement of atoms from the melt to the solid crystallized weld metal) develop. In this layer a region of concentration-induced densification δ is singled-out [8] and diffusion processes in this region (δ), as well as in the liquid and solid phase are considered [5, 6]. Such an approach was used in all the works, devoted to studying MF impact in arc welding on refinement of weld structure.

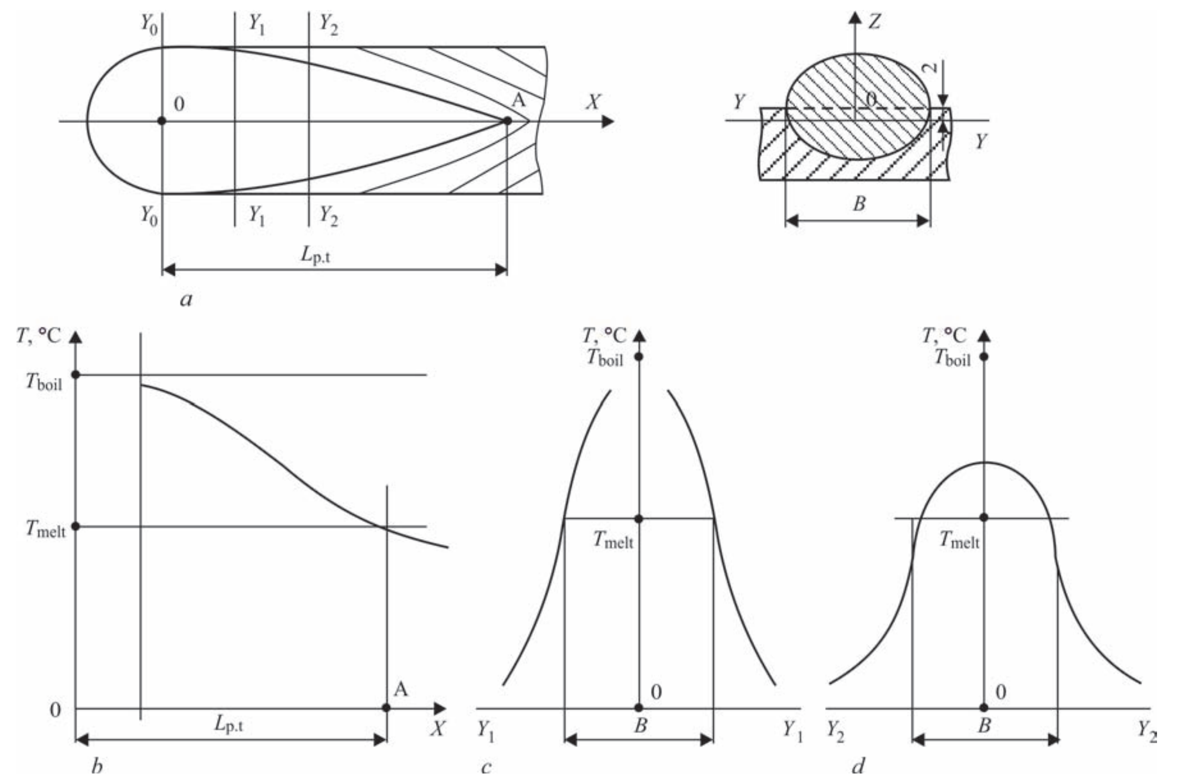
It should be noted that crystallization of weld metal is similar to crystallization of ingots in conventional casting processes in casting and metallurgical productions. At present there is a tremendous number of works (studies) on casting and metallurgical production, in which the mechanism of ingot crystallization is treated differently.

The objective of this work is analysis of published data on the cluster model of the structure of liquid metals and alloys for the case of pool metal crystallization in arc welding with the impact of controlling magnetic fields.

The model of cluster structure of liquid metals and alloys is taken as the base in works on ingot crystallization. The data of these works, in our opinion, are useful at consideration of weld crystallization in arc welding with MF impact.

Let us consider the essence of the problem in greater detail. Diffraction of X-rays, electrons and neutrons, reflected from liquid metals and alloys (also iron-based), revealed the presence of crystal-like components — clusters in the liquid [9–14].

A cluster is a crystal-like concentration of atoms [13]. Clusters form at melting of crystalline bodies [9,



View of the weld pool (*a*) and scheme of temperature distribution in the weld pool ($Z = 0$): *b* — along the pool; *c* — along axis Y_1–Y_1; *d* — along axis Y_2–Y_2

10]. Cluster lifetime is equal to 10^{-7}–10^{-8} s, which is much greater than the period of atom oscillation in the crystalline lattice (10^{-14}–10^{-13} s). Clusters are short-lived, but quite stable atoms groups [10, 11]. A softened zone exists around the clusters (i.e. liquid metal atoms). One cluster of liquid metal (of iron-based alloy) contains about 10^2–10^3 atoms [12, 13]. The volume of the softened zone is equal to 2–5 % for many liquid metals and alloys [9, 10, 19]. The softened zone is an intermediate medium, through which the atoms pass from clusters to other clusters [12]. The publications on casting and metallurgical production consider the «solid-liquid metal» processes in detail, proceeding from the hypothesis of cluster structure of liquid metal [9, 14–18].

The mechanism of liquid metal crystallization is interpreted as follows. Researchers assume that the liquid already contains crystal-like groups (clusters). It is convincingly shown that the earlier used diffusion mechanism of crystallization does not stand scrutiny, as the process of crystallization is approximately 2 to 3 times faster that the rate of diffusion (self-diffusion) of atoms in liquid metals. The diffusion mechanism of crystallization implies formation of a monoatomic layer of the solid phase on the solid phase. It is proven, however, that at crystallization, the atoms form a step, the size of which is several orders of magnitude greater than that of the atom [9]. An elementary block of crystal growth is a certain larger formation, larger than the atom, namely a cluster [9, 10]. Crystal growth due to cluster bonding to the solid phase, does not exclude the possibility of simultaneous occurrence also of bonding of individual atoms. This process, however, is kind of complementary [10].

The above-mentioned crystallization mechanism is theoretically substantiated in works [15–19]. In the thesis [18] mathematical modeling confirmed this crystallization mechanism of iron-based alloys. Obtained model structures are attributed to presence of two stages of the alloy crystallization process. At the first stage clusters are formed in the boundary layer, and at the second stage their subsequent bonding to the cluster-rough surface occurs [18].

In our opinion, the mechanism of the impact of external (controlling) MF on the process of melt crystallization in the pool in arc welding can be explained as follows, on the base of the concepts of liquid metal (alloy) structure in the form of clusters. As is known, the liquid metal in the pool head part in welding iron-based alloys has the temperature of not less than 2500 °C (this temperature reaches the boiling temperature, T_{boil} under the arc). Metal temperature decreases smoothly in the direction of the pool tail part to melting temperature, T_{melt} ($T_{melt} \approx 1500$ °C). Measured by thermocouple immersion into the pool liquid metal in arc welding to the depth of 2 mm from the plate surface, the data of work [20] on the temperature of liquid metal in the pool are schematically given in the Figure. A temperature gradient of liquid metal is observed in the direction towards the tool tail part (Figure *b*). Temperature gradient is even more pronounced in the pool transverse sections (Figure, *c*, *d*). It should be noted that a similar temperature gradient is in place in the direction towards the pool bottom (along *OZ* axis in Figure, *a*). That is the process of crystallization of the pool liquid metal starts on the side walls and at the bottom of the pool, and moves to the pool tail part (up to point *A* in the Figure *a*, *b*, where $T = T_{melt}$). As was convincingly shown in [1], in welding with the impact of alternating LMF (and TMF acc. to our research) the pool liquid metal from the head part, overheated almost to $T = T_{boil}$, periodically moves to the pool tail part, and then to the pool head part. In [1], it is established that temperature gradient before the crystallization front reached 350 °C at some TMF frequencies.

In [9, 10, 12] it was found that at liquid metal overheating, the number of clusters in it becomes greater, and their dimensions become smaller. Considering the data of works [9, 10, 14–19] on cluster mechanism of crystallization and their competitive bonding to the pool solid substrate, it should lead to refinement of the primary structure of weld metal in welding with MF impact that is exactly what was observed in works [1–4].

Conclusions

1. Analysis of publications on metallurgical and casting production showed that many authors support the hypothesis of cluster structure of liquid metals, which was established by diffraction of X-rays, electrons and neutrons from their surface. Here, the ingot structure forms with participation of clusters in the liquid metal.

2. It was suggested that in arc welding with the impact of controlling magnetic fields, the overheated liquid metal from the pool head part, having finer clusters, periodically reaches the crystallization front in its tail part and leads to refinement of the primary structure of the welds.

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Received 23.10.2018