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THE INFLUENCE OF NON-METALLIC INCLUSIONS ON HOT ROLLING CRACKING DEFECTS OF INDUCTION-MELTED Fe-Mn-Al-Si-Ni-Cr-V-C LIGHTWEIGHT STEELS

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The production of Fe-Mn-Al-C steels remains an expensive and difficult process due to a number of features, associated with their chemical composition. Small volumes of such steels are conveniently smelted in vacuum induction furnaces [1]. In laboratory smelting conditions, the weight of ingots usually does not exceed several kilograms, and for industrial installations it may reach 400 kg. Methods, based on arc remelting, are the most suitable for production of commercial volumes of high-manganese steels with a high aluminum content [2].

The need for a protective environment and refining of Fe-Mn-Al-C steel melts is explained by the peculiarities of their chemical composition and sensitivity to the content of impurities [3]. Due to the high content of aluminum and manganese, they are prone to liquation, gas saturation and the formation of various types of oxide inclusions with different sizes and location. The presence of oxide films, carbide eutectics, oxy-sulfide and oxynitride inclusions at grain boundaries in the metal volume is especially harmful for steel mechanical properties and deformability [4]. The investigation of lightweight Fe-Mn-Al-C steels production in conditions of open induction smelting is poorly studied. It requires the analysis of structural-phase characteristics and the non-metallic impurities formation and location features to establish their influence on the destruction of as-cast samples during hot plastic deformation.

To provide investigations of described problem, Fe-26Mn-10Al-1.2Si-3Cr-3Ni-1.4C-0.1V (% wt.) steel was smelted by using open induction furnace. The sulfur and phosphorus content in the steel was 0.03 and 0.04 % wt. respectively. Such chemical composition was chosen by considering the ability of chromium and nickel to increase the strength and heat resistance of the studied type of steels and improve their ability to high-temperature deformation [5]. Vanadium was used for grain-refining and like the element that can form strengthening carbides together with chromium. At the same time, the selected chemical composition could cause the formation of phases that could serve as a material degradation factor. These include carbides, nickel aluminide, eutectics components, oxides and nitrides. For example, chromium and nickel stabilize austenite and significantly strengthen steel, but they can also cause an increase the content of oxides, nitrides and oxynitrides non-metallics. Chromium can also contribute to the formation of phosphides and complex M_7C_3 carbides [6]. Most of these issues for steels with such a complex chemical composition are unexplored for the initial as-cast state in the context of the open induction melting application and their subsequent hot plastic deformation.

Next types of charge materials were used to smelt experimental steel: C45-steel with 0.45 % wt. carbon content; Al-12Si aluminum alloy scrap; Al-10V master-alloy; metallic Mn, Al, Cr, Ni and V of ordinary purity. Graphite powder served as an additional source of carbon.

Melting was carried out in a 40-kW open induction furnace. Its heating zone was made of Al_2O_3:MgO=80:20 mixture. The charge materials were melted in the furnace gradually. At the first step, the formation of a steel melt was achieved by adding carbon directly before liquid metal bath forms. After that, up to 30 % required content of the aluminum and manganese was added. After the melt reached the required temperature 1400-1500 °C, the procedure was repeated with the addition of chromium and nickel every five minutes. Addition of CaO, magnesium and lanthanum (as a part of the Ni-16Mg and Al-40La master-alloys) was provided at the finishing part of melt preparation to increase purification of the alloy from harmful impurities. At that time and after it, melt was mechanically stirred and the slag was removed. After melting all the components and reaching a temperature of 1500 °C, the liquid metal was purged with argon three times for 10 seconds each and the remaining slag was removed. Gases content monitoring wasn’t provided, during all the melt preparation process.

10 kg of melt was poured from 1450 °C into a sand mold with a liquid glass binder through feeders from below (siphon pouring). Also, exothermic elements were placed in the mold to eliminate the shrinkage defects of the ingot. As a result, a plate-like casting with a 20 mm wall thickness was obtained.

The feeding system of the ingot and its upper part with reduced shrinkage cavity were separated from the main part of a billet, intended for further hot plastic deformation. First, it was subjected to homogenization annealing at 1050 °C for 90 minutes in a resistance furnace. After that, the billet was deformed in a rolling mill with a compression rate 1 mm in one pass. After every two passes, the workpiece was returned to the furnace, reheated to the annealing temperature, held for 10 min, and the deformation was repeated.

The plate was fractured during the second deformation step at the stage when the thickness of the workpiece reached 16 mm. Fractured billet was purposely broken after slow air cooling in such a way to connect several hot cracks and to obtain a sample with minimum inner oxidation for fracture surface studies.

To determine the causes of a Fe-26Mn-10Al-1.2Si-3Cr-3Ni-1.4C-0.1V steel fracture under the action of hot plastic deformation and the influence of non-metallic inclusions and defects on it, electron microscopy and X-ray phase analysis were carried out.

Microstructure and phase analysis of open induction melted Fe-26Mn-10Al-1.2Si-3Cr-3Ni-1.4C-0.1V steel showed that main formed defects in as-cast state are: columnar structure, microliquation areas, oxide films and structure difference, caused by crystallization speed divergency. They lead to downgrade of steel properties and especially – high temperature deformability.

Non-metallic inclusions in obtained Fe-Mn-Al-Ni-Cr-V-C steel are mainly formed by two sources. The first one is typical, when the melt cannpt be purified from inclusions due to their small dimensions. The second one consist of melt surface oxidation while pouring it into a mold. The last reason prone formation of oxide films and can be eliminated by controlling pouring process and atmosphere.

Despite the presence of oxide films, the formation of hot cracks in researched steel was caused mainly by columnar structure, performed by two types of austenite (ordinary one and hardened – more saturated with carbon and nitrogen) and spot-like aluminum and manganese oxides. High temperature also provides carbides formation, some of which precipitate at the grain boundaries near eutectic volumes, making them more spread and harmful. Named factors contribute deterioration of grain boundaries quality and radically prone intergranular crack formation.

To eliminate investigated disadvantages, melt protection from oxidation while pouring it into a mold should be provided as well as grain refinement. First action will reduce melt saturation with oxygen and nitrogen, also minimizing oxide film formation. The second one will provide more desirable structure, minimization of liquation and eutectic formation and more even distribution of fine non-metallics.

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