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Different techniques of determination of the cracking criterion for solidification in casting

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Abstract

Cracking which occurs during the solidification process is a serious defect in castings and welds. Alloys are susceptible to cracking during solidification. Al alloys, stainless steels and Ni-base alloys are notable examples. Cracking takes place in the semisolid region called the mushy zone. During solidification, shrinkage and thermal contraction of the mushy zone and its surrounding solid are hindered, tensile deformation can induce cracking (in the semisolid region) along grain boundaries that are not fed with sufficient liquid phase. The cracking criterion is focused on events occurring at the grain boundary, including separation of grains from each other, lateral growth of grains toward each other, and liquid feeding between grains. The susceptibility factor of a binary aluminum alloy to cracking during solidification was also described. The criterion has an effect upon: (a) the lateral growth rate of two neighboring grains toward each other to bond together to resist cracking, and (b) the length of the grain-boundary liquid channel through which feeding has to occur to resist cracking. In future work the criterion will be compared with experimental data and computer simulation during solidification of binary aluminum alloys in welding.

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1. Introduction

In the case of casting it is reffered to as hot tearing (hot cracking), whereas in the case of welding it is called solidification cracking. It is a serious defect in welds and castings, which occurs during solidification. Due to low recurrence of the phenomena, such as the evolution of grained structure or stress redistributions, the susceptibility to hot cracking can be estimated only in an approximate way. Predicting the manner of hot tears is thus an important issue in industrial practice. The paper delineates the various hot tearing criterions, known from the literature, for welds and castings. Cracking during solidification is caused by shrinkage which in turn is caused by higher density of the solid than the liquid. Thermal contraction, on the other

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hand, is associated with the thermal expansion coefficient of materials [1]. In casting, shrinkage is impeded by the rigid mold walls, especially those of metal molds. In welding it is obstructed by the rigid body of the workpiece clamped down or connected to. The production technology that involves many significant factors has an impact on the end result, that is on the quality of the cast and the weld. In shape casting, an equiaxial structure is formed [2]. During solidification processes, various types of defects may appear in the solid-liquid areas. These areas solidify as the last batches of material. The shrinkage leads to micro-porosity effect [3]. Hot tearing of solid-liquid areas occurs when the stresses acting on them are able to break the backbone of solid phase, filled with the liquid phase.

Hot tearing remains a major problem of casting technology despite decades of efforts to develop working hot tearing criteria and to implement them into casting and welding computer simulations. Existing models allow for the calculation of the stress-strain and temperature situation in a casting and for comparing these with the chosen hot tearing criterion. In most successful cases, the simulation shows the probability of hot tearing and the sensitivity to such process parameters as casting speed, casting dimensions or casting recipe. However, none of the existing criteria can provide a certain answer to whether the hot crack will appear or not and what will be the extent of hot cracking (position, length, shape). Modern hot tearing model, a criterion based on this model and the future development of hot tearing research should be conducted in terms of mechanisms of hot crack nucleation and propagation. It suggests that the new model and criterion should take into account different mechanisms of hot tearing which operate at different stages of solidification and base on fracture mechanics, i.e., include the mechanisms of nucleation and propagation of a crack [4].

2. Description of the cracking criterions in solidification

Hot tearing – a severe defect occurring during solidification is the conjunction of tensile stresses which are transmitted to the mushy zone by the coherent solid skeleton and of insufficient liquid feeding to compensate for the volumetric change. Hot cracking was and still is of interest to founders and scientists [5, 6, 7, 8, 9, 10, 11]. Initially, in the casting solidification, the problems of hot tearing formation were solved by experimental estimation. Unfortunately, the studies mostly focused on the formation of a single crack, which was not fully applicable in the industrial practice. The next step in the development of testing methods for hot tearing occurrence was the use of advanced numerical methods. Approaches based on computer simulations can be divided into two groups. The first group concerns the analysis of the development of a single crack, whereas the second group involves an extensive analysis of thermomechanical phenomena. The analysis of thermomechanical phenomena allows to draw conclusions for assessing the degree of risk of appearance of the defects in the continuity. The use of such approach is also possible while performing simulations with the use of commercial engineering programs. Usually, such programs do not provide any criteria for hot tearing evaluation. Users of this kind of software have to choose which of the available values characterizing the state of stress and/or deformation should be used for the rupture susceptibility assessment. In that case creating their own programs dedicated to the considered problem and taking the chosen criteria into account can be helpful. It should be mentioned, that such an analysis requires good knowledge of the phenomena in casting or welding formation and skills in simulation of these phenomena. Specialized engineering software, usually based on the finite element method, is also required [12]. On the other hand, computer simulations performed with the use of such software are very time consuming.

In casting, the hot cracking of metals has been studied using various manners. One of the criteria is designed to determine the tensile stresses by constraining some parts of the casting. The part which is in the middle of the casting solidifies later than other parts. The middle part is under tensile stress along the skeleton direction and cracks form in the perpendicular direction. Using such an approach, Clyne and Davies [13] introduced a Cracking Sensitivity Coefficient (CSC) which is given by the ratio of two times:

$$CSC = \frac{t_v}{t_r} \tag{1}$$

where t_v iis the time during which the mushy zone is susceptible to hot tearing and t_r is the time during which stresses can be relaxed. The authors have considered that the permeability between these two areas is supposed to be such that feeding can heal an opening of the mush.