Journal of Materials Processing Technology 221 (2015) 121–127

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Analysis of the evolution behavior of voids during the hot rolling process of medium plates

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ARTICLE INFO

Article history:
Received 21 October 2014
Received in revised form 4 February 2015
Accepted 7 February 2015
Available online 16 February 2015

Keywords:
Void
Hot rolling
Evolution behavior
Finite element simulation

ABSTRACT

Void defects such as porosity, shrinkage, and the formation of gas cavities cannot be completely avoided during the casting process. One current method that improves the quality of these products is the use of a forging or rolling process. Further research on the evolution behavior of voids during processing is necessary. To this effect, the present study investigates the evolution behavior of a few different sizes of voids during the hot rolling process. Evolution behavior is analyzed by finite-element simulation and laboratory experimentation. Analysis focused on the stress field surrounding a void during the rolling process. Results showed that voids changed shape from spherical to ellipsoid, and as the rolling pass increased became smaller and more irregular. The upper and lower surfaces of the voids bonded together after the last rolling pass. Voids of varying size change shape in a similar manner, however, by analyzing their hydrostatic integration it was observed that smaller voids bond more readily than larger ones. The results demonstrate favorable agreement between experimental and simulated results.

1. Introduction

Due to solidification shrinkage during the casting process, void defects like porosity, shrinkage and gas cavities cannot be avoided. Sigworth and Wang (1993) have built a thermodynamic model to predict when porosity may form. Many scrap castings are abandoned because of void defects. Void defects in the final product affect the quality of the product and shorten its service time, which must be healed during subsequent forming process such as forging or rolling, otherwise they may lead to catastrophic failure during service.

The elimination of void defects includes two stages during forging or rolling process: void closing and surface bonding. Most of void defects can be eliminated by intensive plastic deformation. During the forging or rolling process, high temperature and stress are imposed on the voids, which makes the elimination of the void defects relatively easy to achieve. Requena et al. (2014) investigated in situ by synchrotron microtomography focusing on the effect exerted by the stress triaxiality induced by different sample geometries, they found that voids nucleated during two consecutive deformation steps. Wang et al. (1996) have investigated the closure and welding phenomena of cylindrical and round voids in a slab during hot rolling, and found that large rolls were effective for the void closure. Park and Yang (1997) investigated the bonding process of void during hot-forging under different conditions of working temperature. They found that the height reductions for void closing, contacting and the bonding of internal void surfaces have been obtained with respect to void position. Huang et al. (2007) studied the diffusion welding process and mechanism of internal porosity defects in heavy forging. Zhang et al. (2009) have proposed a criterion for spherical void closure. The research results show that the influence of pressure, temperature and holding time on the diffusion welding quality is very important.

Forging and rolling are two different processes to produce steels and show different deformation behaviors, productivity and cost. Many previous studies have reported closure behavior of voids during forging and rolling. Kakimoto et al. (2010) investigated the relationship between the reduction ratio and the void shape/void position for hot forging. Lee et al. (2011) studied the closure of voids during open die forging, they found that a local effective strain value of 0.6 or greater must be achieved for void closure during forging. Chen (2006) has used the finite element method of continuum mechanics to investigate the void closure behavior inside a porous metal sheet during the sheet rolling process, where it was found

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http://dx.doi.org/10.1016/j.jmatprotec.2015.02.012
0924-0136/

Table 1
Chemical composition of the workpiece (wt%).

C	Si	Mn	P	S	Nb	Ti	N
0.16	0.16	1.16	0.0118	0.0032	0.014	0.017	0.0146

that the relative density is greatest at the front and rear regions of the internal void after rolling process. Chen et al. (2011) have established a comprehensive three-dimensional finite element model to predict void closure behavior by using an aluminum sheet during flat cold rolling, and found that void diameter and roller diameter have a significant influence on void closure. Deng et al. (2009) studied the closing behavior of defects in continuous casting steel slabs during rough transverse rolling. It was observed that surface defects require the largest critical reduction for closure, and that critical reduction of defects is lowest at a 1/8 thickness. Hwang and Chen (2002) explored the effect of friction on void closure during cold rolling. Nakasaki et al. (2006) researched on the application of hydrostatic integral parameters to rolling. Their results showed that as the friction factor increases, the final void length increases.

All these studies provide valuable information, however incomplete, as they mainly focused the parameters which influence void closure, mostly during hot forging. There is some research to be found for void behavior of non-steel for cold rolling. Ours is the first study which explains the mechanism of void closures during hot rolling.

In this paper, void formation, evolution and closure during the hot rolling of medium plates is investigated through experiments and a 3-D non-linear finite element model. The model was developed and implemented using the commercial finite element code Forge2011. The morphology and stress fields of the voids are also analyzed. The hydrostatic integration, G_m, of voids with varying diameters is discussed.

2. Finite element modeling verification

A thermal–mechanical coupling mode was performed, the heat transfer coefficients between slab and atmosphere was assumed to be 80 W/(m^2 K) and environmental temperature was 25 °C. The coulomb friction model was used, the friction coefficient was assumed to be 0.3. The heat conductivity between the slab and roll was assumed to be 46 W/(m K). In order to verify the accuracy of the finite-element model, a series of experiments with an A32 steel specimen were performed. A cylindrical void was created in the center of the specimen by electric spark cutting. The diameter of this void was 8 mm, and its depth was 10 mm. In order to avoid oxidation during the heating process, the void was covered by argon arc welding. In order to ensure the rolling temperature, the specimen was heated up to 1200 °C and held for 2 h in reheating furnace. The initial rolling temperature was 1020 °C. The schematic of the experiment was shown in Fig. 1. The size of plate specimen is 250(L) × 75(W) × 90(H) mm, the roll radius is 190 mm and the rolling speed is 0.6 m/min. The chemical composition of the material (A32) is clear from Table 1 and rolling schedules are listed in Table 2. The main material parameters are shown in Table 3. The flow stress curve of the material (A32) at different temperature was shown in Fig. 2.

Fig. 3 shows evolution behavior of voids during the rolling process by finite-element simulation and laboratory experimentation.

Table 3
Material parameters.

Parameters	Steel	Roll
Density (kg/m^3)	7830	7850
Young's modulus (GPa)	105	210
Poisson's ratio	0.36	0.3
Specific heat (J/(kg K))	778	778
Thermal conductivity (W/m^2/°C)	35.5	34.4

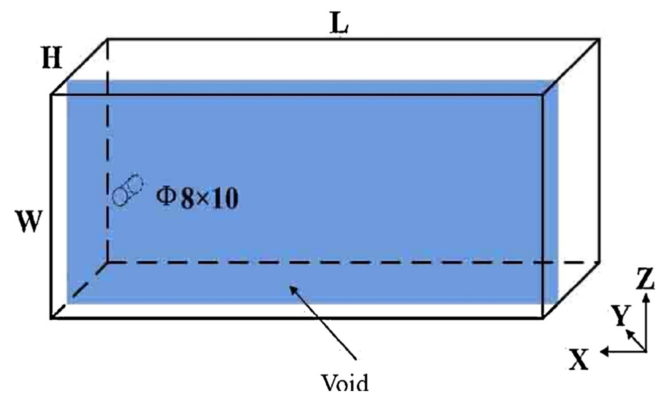

Fig. 1. Schematic diagram of void in specimen.

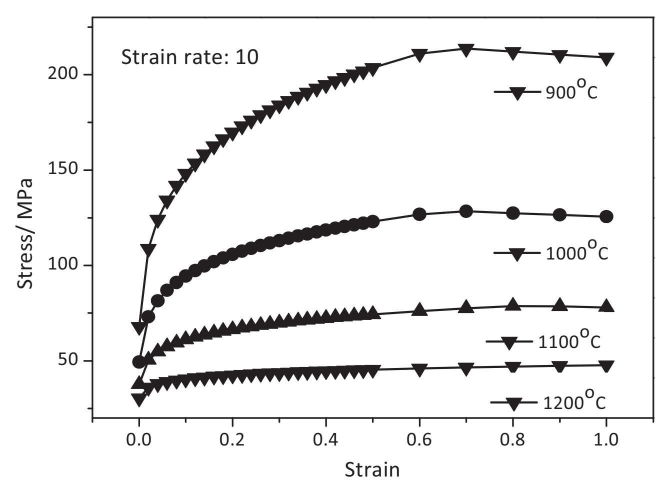

Fig. 2. Flow stress date of A32 at different temperature.

Similar results were obtained through both experimentation and simulation. The morphologies of the voids were similar after the rolling process, showing only a small difference in the final bonding stage. This is caused by the model's inability to consider the dynamic recrystallization that occurs during the rolling process. (These small differences do not affect the analytical process.) Overall, the model correctly predicts the evolution behavior of voids during hot rolling, and is suitable for research. Change of width and height of voids were shown in Fig. 4.

Fig. 5 shows morphology of voids in continuous casting slab. By analyzing the shape characteristics of voids in a continuous casting slab with electromagnetic stirring and soft reduction, it is observed that most of the voids are spherical possess diameters near 3 mm.

Table 2
Detailed hot rolling schedules of experimental.

Rolling pass	0	1	2	3	4	5	6	7
Thickness (mm)	90	75.6	66.2	58	49.8	41.6	33.5	25.5
Rolling reduction		16%	12.4%	12.4%	14.1%	16.5%	19.5%	23.9%
Rolling temperature (°C)	1020	1020	1013	1008	1005	995	993	980