International Journal of Machine Tools & Manufacture 48 (2008) 1626–1636

Contents lists available at ScienceDirect

International Journal of Machine Tools & Manufacture

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

Vacuum-assisted rheo-forging process of A356 aluminum alloys

H.H. Kim [a], C.G. Kang [b,*]

[a] Precision Manufacturing Systems Division, Pusan National University, Pusan 609-735, Republic of Korea
[b] School of Mechanical Engineering, Pusan National University, Changjun-don San 30, Pusan 609-735, Republic of Korea

ARTICLE INFO

Article history:
Received 3 March 2008
Received in revised form
22 July 2008
Accepted 24 July 2008
Available online 5 August 2008

Keywords:
Rheo-forging
Electromagnetic stirring system (EMS)
Porosity
Pinhole
Vacuum pump

ABSTRACT

In recent years, various rheo-forming methods have been developed to produce products with improved mechanical properties. To this end, rheo-forging of metal offers not only superior mechanical strength but also requires much lower machine loads than solid forming processes. However, there are many problems, such as air indraft during the stirring of the molten metal as well as the expense of the starting materials. As a result, the commercial availability of products formed through semi-solid processes is still limited.

Semi-solid materials with a desired microstructure are produced by stirring during solidification from their molten state. Occasionally, indraft of air has degrades the resultant mechanical properties. This paper presents the results of the influence of air control during stirring and forging. A356 aluminum alloys were prepared by electromagnetic stirring under vacuum in order to prevent the indraft of air and sample parts were subsequently fabricated with hydraulic press machinery. To compare the influence of air control, two type samples were fabricated (1) samples fabricated under vacuum and (2) samples fabricated while open to the free atmosphere. An H-shaped product was formed in order to select and observe the deformation behavior.

1. Introduction

Recently, the rheological processing of aluminum alloys has quickly developed as an alternative to traditional casting and forging processes driven by the demand for light-weight high-performance parts in the automotive industry needed to increase fuel efficiency.

Rheological processing is a net-shape manufacturing method using a material co-existing in the solid and the liquid states. This process is capable of fabricating complex-shaped modules in one process. Because of the high viscosity, the material flow pattern does not become turbulent flow during die filling. Thus, gas-induced defects such as porosity are decreased, leaving only small shrinkage defects as a result of solidification [1–3].

But liquid segregation during semi-solid formation is a source of serious defects that cannot be controlled with heat treatment, causing nonuniformity in mechanical properties. For reduction of such problems, an electromagnetic stirring system (EMS) was adapted to the rheological forming process. Zoqui et al. [4] have observed the evolution of the rheo-casting structure of A356 aluminum alloys stirred by EMS casting process. However, problems such as gas porosity and pinhole effects remain as part of solidification with EMS. Compared with the normal state, stirred molten metal has more oxidization surface and air indraft. This degrades the mechanical properties. In addition, inherent defects such as pinholes cannot be removed by EMS and other stirring systems.

The first attempts to develop methods of vacuum die casting were recently made in hot-chamber die-casting machines [5]. Vacuum technology has also been applied to semi-solid metal (SSM) casting to fabricate a fully heat-treated space frame, which has a large surface area with a thin wall thickness [6].

The aim of the present work is, therefore, to investigate the effect of the vacuum-assisted method on the performance of rheo-forged products and find the optimum fabrication conditions.

2. Experimental equipment

2.1. EMS under vacuum for rheological billet fabrication

In this study, A356 aluminum alloy was used. Its chemical composition is given in Table 1.

* Corresponding author. Tel.: +82 51 510 2335; fax: +82 51 518 1456.
E-mail address: cgkang@pusan.ac.kr (C.G. Kang).

0890-6955/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijmachtools.2008.07.009

To remove oxidization products and hydrogen gas from the molten metal, nitrogen gas was injected into the melt for 15 min. Oxidization products and impurities were thus cleared away from molten metal surface [7].

In aluminum alloys, hydrogen gas readily makes holes within the alloy during solidification. In addition, hydrogen gas has the highest solvency within aluminum alloy compared to other constituents of air, such as oxygen and nitrogen. Consequently, gas hole formation and porosity are increased within the alloy as the temperature decreases, degrading its mechanical properties [8].

Fig. 1 shows that schematic diagram of the EMS and vacuum pump. The EMS system operated with a three-phase current at 60 A. The sleeve and cup are made of a non-magnetic substance. After the molten metal was poured, the injection punch was moved to the surface of the top sleeve and the EMS was operated under vacuum. The gas and air were discharged from the sleeve. This system prevents oxidation of the molten metal and air indraft. The remaining hydrogen gas within the metal is also extracted from it.

2.2. Specimen part dimensions

The rheology billet for vacuum-assisted EMS was fabricated by a press machine. Fig. 2 shows the dimensions of the sample. The H-shaped sample used for analysis of hot and warm forging with preformed shapes, providing a test bed for observation of material flow and formability [9,10].

Table 1
Chemical compositions (wt%) and thermal characteristics of aluminum alloys

	Zn	Mg	Cu	Fe	Si	Mn	Ti	Al	T_L	T_S
A356	0.01	0.33	0.01	0.13	7.00	0.01	0.01	Bal.	614 °C	554 °C

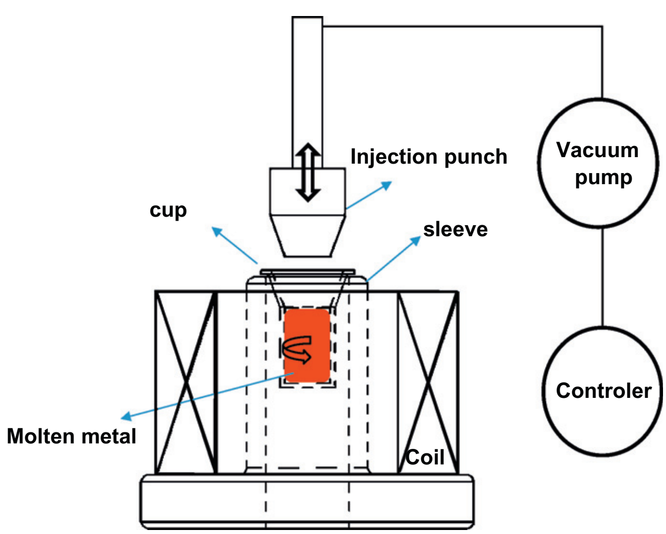

Fig. 1. Schematic diagram of the EMS with vacuum pump.

Table 2
Experimental conditions for A356 by rheo-forging

Pouring billet temperature (°C)	Stirring current (A)	Stirring time (s)	Forging pressure (MPa)	Vacuum pressure (cm/Hg)
555	0	0	250	76
563	0	0	250	76
568	0	0	250	76
580	0	0	250	76
600	0	0	250	76
555	60	60	250	76
563	60	60	250	76
568	60	60	250	76
580	60	60	250	76
600	60	60	250	76
580	60	60	250	66
580	60	60	250	56
580	60	60	250	46
580	0	0	250	66
580	0	0	250	56
580	0	0	250	46
580	0	0	200	76
580	0	0	225	76
580	0	0	250	76
580	60	60	200	56
580	60	60	225	56
580	60	60	250	56

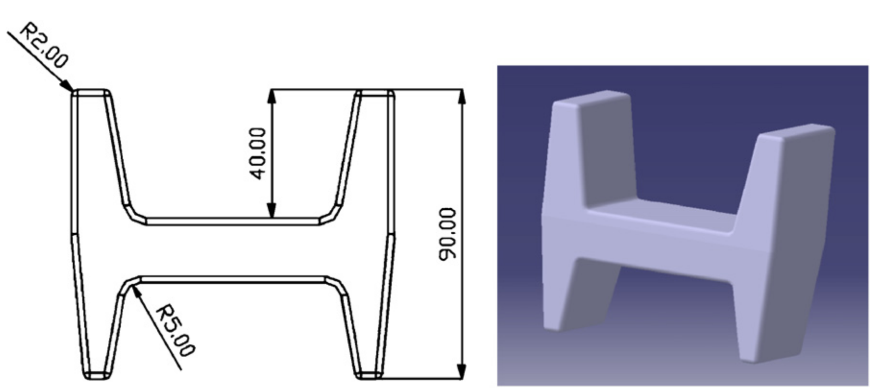

Fig. 2. Dimensions of the test article.