Aluminium Alloys
Processing and Techniques

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Edited by **Sally Renwick**

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Preface

Every book is initially just a concept; it takes months of research and hard work to give it the final shape in which the readers receive it. In its early stages, this book also went through rigorous reviewing. The notable contributions made by experts from across the globe were first molded into patterned chapters and then arranged in a sensibly sequential manner to bring out the best results.

Last few years have witnessed breakthrough in production of aluminium alloys. New procedures of welding, casting, forming and surface modification have emerged to advance structural integrity of aluminium alloys. This book aims to serve the needs of a broad spectrum of professionals ranging from academic to industrial communities by providing latest information. It also serves the purpose of assisting technocrats, entrepreneurs and other individuals interested in the application and production of aluminium alloys. It will also serve as a reference to teachers teaching at senior and graduate level to support their text.

It has been my immense pleasure to be a part of this project and to contribute my years of learning in such a meaningful form. I would like to take this opportunity to thank all the people who have been associated with the completion of this book at any step.

Editor

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Part 1

Casting and Forming of Aluminium Alloys

1

Aluminium Countergravity Casting – Potentials and Challenges

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1. Introduction

Counter-gravity casting, also called vacuum casting, is a mould filling technique in which low pressure created inside a mould cavity, causes prevailing atmospheric pressure on the melt surface to bring about an upward or counter-gravity movement of the melt into the mould cavity. The process was patented in 1972 by Hitchiner Manufacturing (Lessiter & Kotzin, 2002) and different variants of the process had evolved over the years. Greanias & Mercer (1989) reported a novel valve system that could potentially increase throughput by allowing mould disengagement prior to solidification while Li *et al* (2007) have developed a multifunctional system aimed at aggregating different variations of the technology into a single equipment.

The unique mould filling approach of the countergravity casting technique confers on it a set of unique advantages related to casting economics, defects elimination and attainment of net-shape in cast products. Such desirous attributes has ensured the growing importance of the technology, especially in power and automotive applications. A testament to the rising profile of this casting technique is its adoption in the production of a range of parts such as compressor wheels for turbo-chargers (TurboTech, 2011), automotive exhaust manifolds (Chandley, 1999) and a high-volume production (130,000 units/day) automotive engine Rocker Arm (Lessiter, 2000).

The growing importance of this casting technique in some metal casting sectors notwithstanding, there is scant awareness and interest in many mainstream casting spheres. This chapter thus seeks to present a technology overview of the countergravity casting technique. The shortcomings of conventional processes are highlighted alongside the unique advantages of the countergravity technique. Challenges of the countergravity technique are also presented with discussion of efforts and prospects for their redemption.

2. Description of the countergravity casting process

The basic process steps for the vacuum casting process are presented as follows. In the diagram in figure 1, a preheated investment mould with an integrated down-sprue (fill pipe) is positioned in the moulding flask.

The sprue, with a conical-shaped intersection point with the rest of the mould, pokes through and sits in the conical depression of the lock-nut. The "square" fit of the two, depicted in figure 2, ensures a sealing of the flask interior from the external environment.

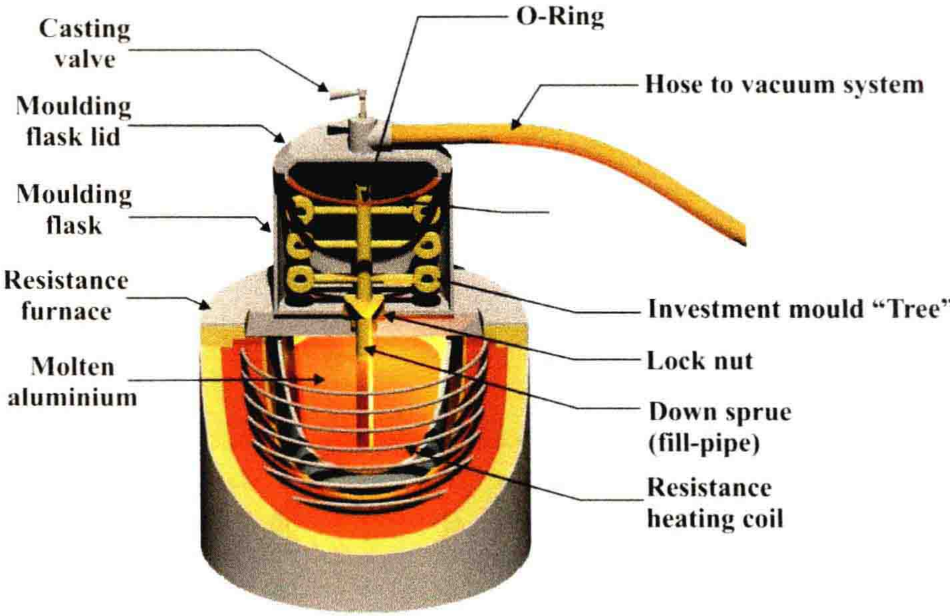

Fig. 1. Typical setup of the countergravity casting process

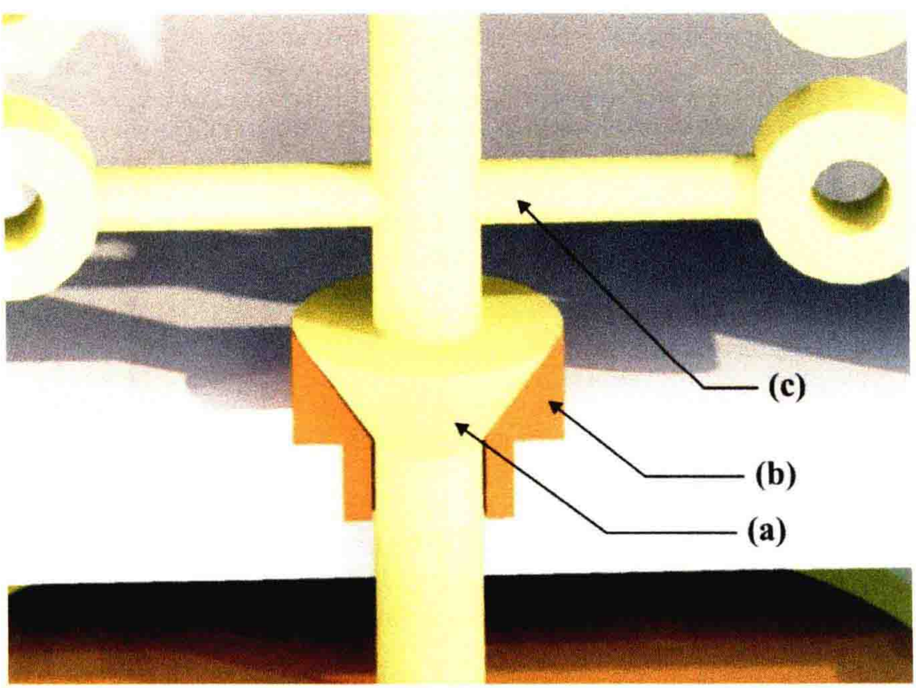

Fig. 2. Down sprue, with conical base (a) is integrated with the rest of the investment mould "tree" (c). The assemble rests inside the conical depression of the lock-nut (b)

The otherwise solid investment mould is made permeable by a single opening at its apex. This opening effectively connects the mould cavity with the interior space of the moulding flask, making it an extension of the moulding flask and enabling its evacuation along with the rest of the flask. The flask lid hosts the casting valve, a connecting hose to the vacuum system and lid locking mechanism. The electrical resistance furnace melts the aluminium charge, usually by a superheat of about 40 °C above the melting temperature (660 °C) of aluminium to reduce melt viscosity and ease melt up-flow into the mould. During countergravity casting, the moulding flask with the mould assembly inside, is placed on the furnace lid with the down-sprue poking through a hole in the furnace lid.
The vacuum system evacuates the moulding flask and the ensuing low pressure thus created causes ambient atmospheric pressure on the melt to push up the molten metal, up inside the mould. See figure 3.

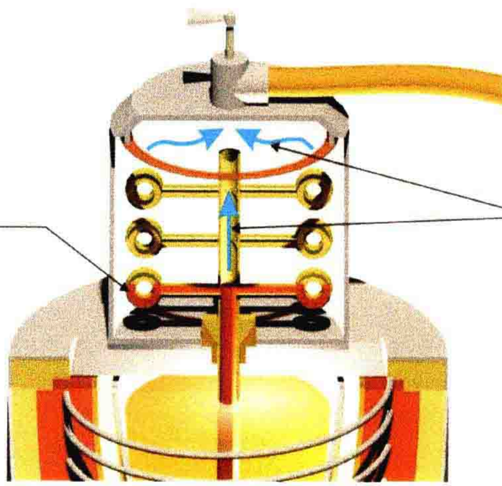

Fig. 3. The evacuation of the moulding flask (a) also evacuates the investment mould cavity. This causes molten aluminium to rise up into the mould cavity (b)

Apart from investment material, the mould could be a metal mould or a ceramic mould. The vacuum system is calibrated so that just the right volume of melt flows inside the mould for a period long enough for the melt to solidify. The vacuum is released after allowing enough time for melt solidification in the mould cavity. This allows un-solidified melt along the sprue length to be flow back into the furnace. The illustration in figure 4 shows the vacuum being maintained until the cavity is completely filled. Vacuum pressure is then released causing un-solidified melt in the sprue to flow back into the furnace

3. Conventional techniques and casting defects

Conventional gravity- or pressure-assisted aluminium metal casting techniques like sand casting, investment casting and die casting are fraught with problems. These include gas defects, melt oxidation, shrinkage defects and pouring defects. Defects are naturally undesirable because they can result in low strength, poor surface finish and high number of rejects in a batch of cast products.

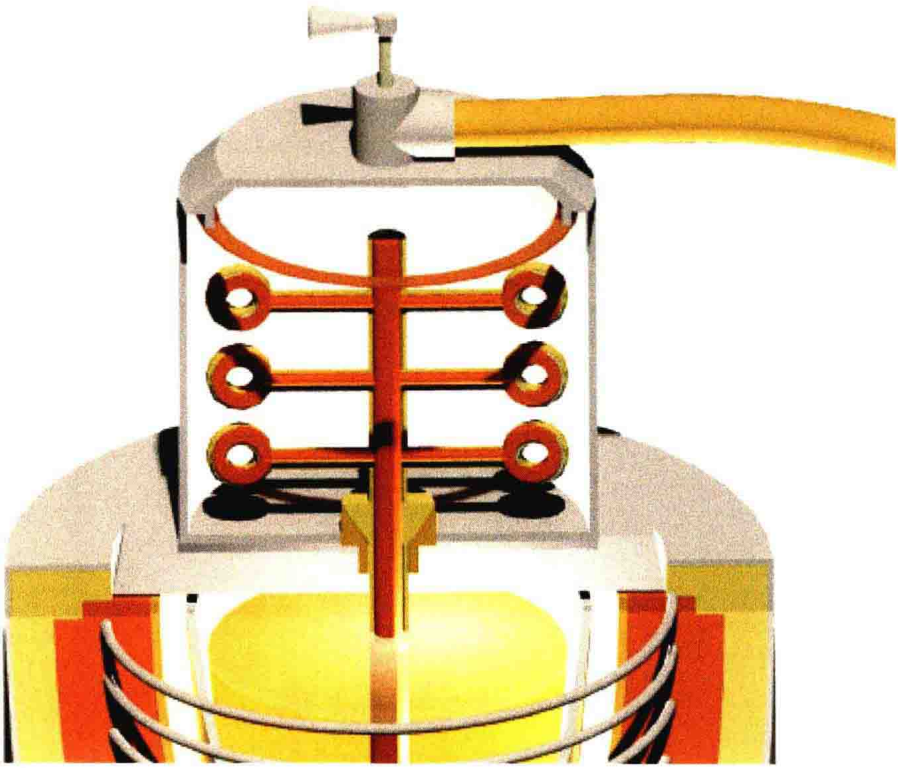

Fig. 4. The vacuum is maintained until the cavity is completely filled. Vacuum pressure is released causing un-solidified melt to flow back into the furnace

3.1 Gas defects

Molten aluminium is particularly susceptible to adsorbing significant quantities of hydrogen gas from atmospheric moisture, which leads to a high concentration of dissolved hydrogen in the melt. This may be further exacerbated by alloying element like magnesium which may form oxidation reaction products that offer reduced resistance to hydrogen diffusion into the melt (Key to Metals, 2010). This causes blow holes and gas porosity which combine to reduce strength of the cast part. The micrograph in figure 5 shows a blow hole defect, it can appear at any region of the cast microstructure and is exacerbated by damp mould materials which give off steam during casting. Figure 6 shows gas porosity defects in an aluminium casting, these are much smaller than blow holes and tend to form in clusters around the region of the grain boundaries.

3.2 Melt oxidation

Oxidation of the melt is another severe defect suffered by aluminium alloy castings. The elevated melt temperature promotes easy oxidation of the aluminium by ambient oxygen. The aluminium oxide thus formed is an undesirable non-metallic inclusion. Considerable efforts, through the use of in-mould filters, protected atmosphere, or alloying additions are often needed to reduce oxide formation and entrainment in the mould.

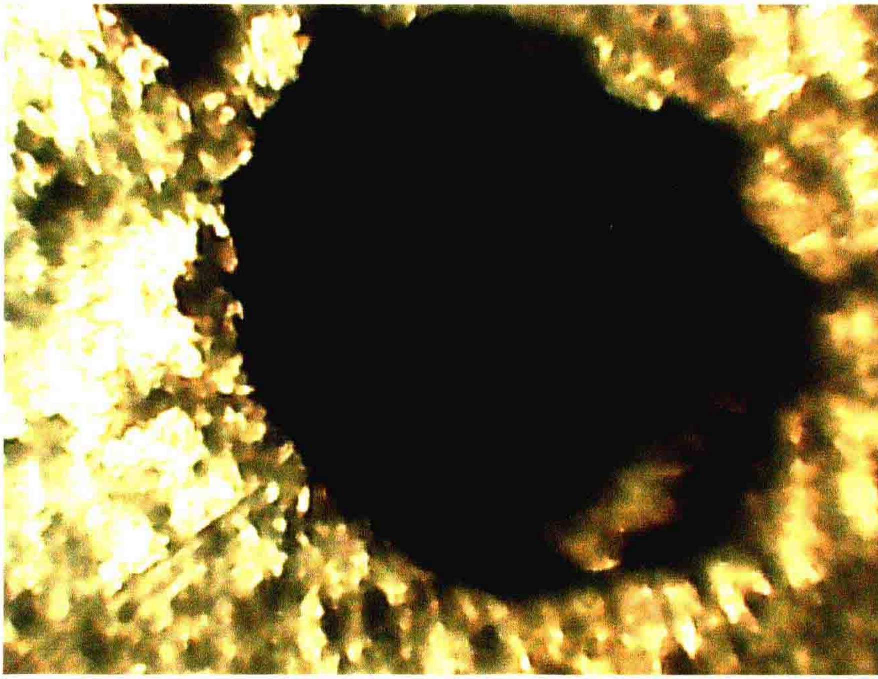

Fig. 5. A Blow hole defect in an aluminum casting at 100× magnification

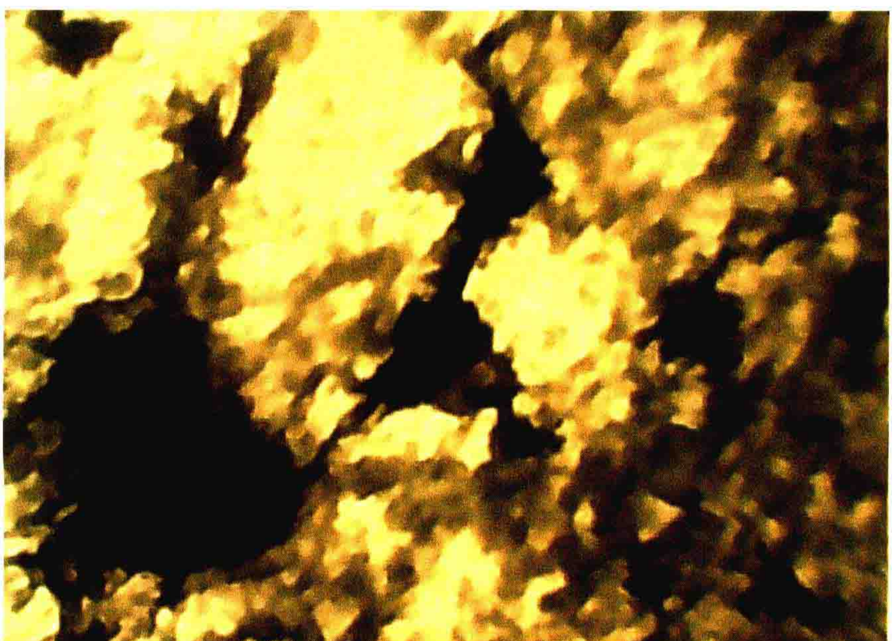

Fig. 6. Gas porosity in aluminium casting at 1000× magnification

3.3 Shrinkage

Shrinkage is the natural consequence of liquid to solid transformation of the melt during cooling and is common in most metals. Shrinkage is particularly severe in aluminium alloys. In aluminium alloys, the volumetric shrinkage ranges from 3.5% to 8% (Kaufman and Rooy, 2004). This manifests as shrinkage cavities in larger portions of the casting.

This is often counteracted by strategic placement of risers. Figure 7 shows the typical appearance of volumetric shrinkage defect in an aluminium section.

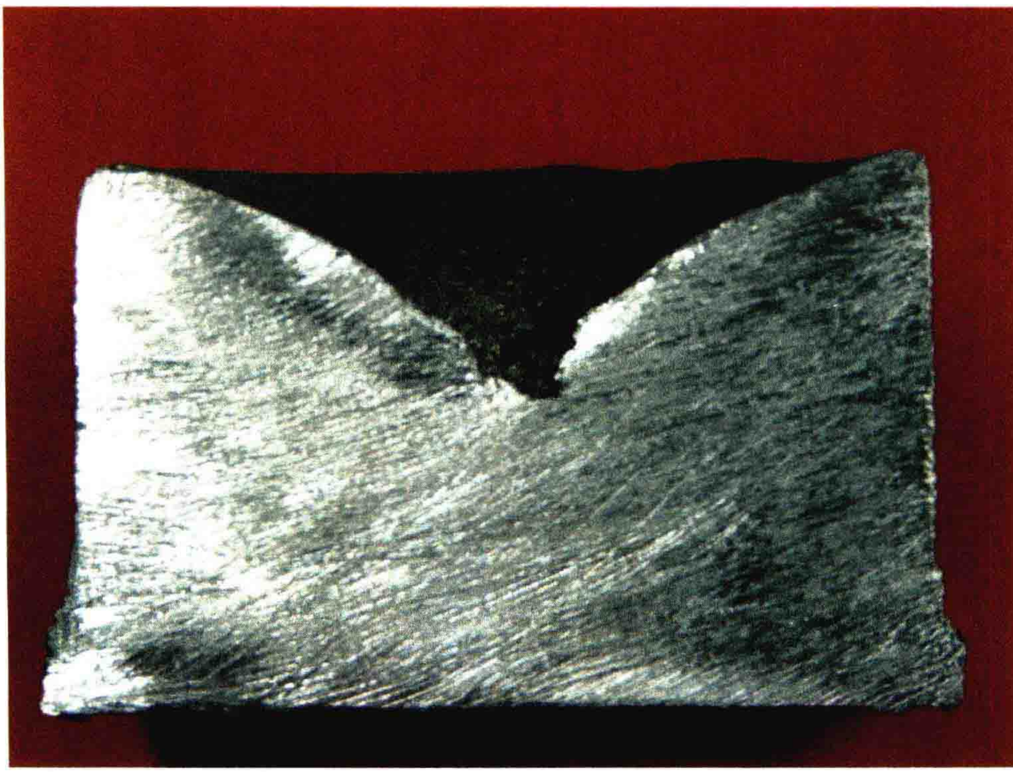

Fig. 7. Typical appearance of volumetric shrinkage defect in an aluminium section

3.4 Pouring defects

During pouring of the melt, there is considerable splashing and sloshing about of the melt. This entrains significant quantities of air and non-metallic inclusions in the mould. Such entrained material degrades casting quality. This problem is often mitigated by incorporation of complex gating systems designed using advanced Computational Fluid Dynamics (CFD) modules. Such casting simulation software is able to predict and avoid bubble streams in metals castings (Waterman, 2010).

Some of the problems outlined above have been resolved by advancements in pressure die casting, improved investment casting techniques and centrifugal casting. These techniques individually solve some, but often not all of the problems with gravity-assisted pour of an air-melt. For instance, in conventional die casting, melt is sprayed at high velocity into the die and cavity-atmosphere tends to be admixed and entrapped in castings during the