JJMIE

Volume 5, Number 6, Dec. 2011
ISSN 1995-6665
Pages 521 - 526

Jordan Journal of Mechanical and Industrial Engineering

Studying the Effects of Varying the Pouring Rate on the Casting Defects Using Nondestructive Testing Techniques

Wisam M. Abu Jadayil*,[a]

[a]Department of Industrial Engineering, The Hashemite University, Zarqa 13135, Jordan

Abstract

In this paper Aluminum casting defects when the pouring rate is varying are investigated using green sand casting process by the aid of two nondestructive testing techniques. Ten Al casting samples have been prepared with different pouring rate for each. Then they have been tested using the Penetrant Test (PT) and the Ultrasonic Test (UT) to describe the surface and subsurface defects respectively. It was found that when the pouring rate is increases surface defects are significantly increases as the penetrant testing results showed. On the other hand when the pouring rate is increases, there are much less defects appeared internally as the ultrasonic testing showed.

Keywords: Pouring rate; Penetrant testing; Ultrasonic testing; Casting defects

1. Introduction

Cast aluminum alloys are widely used in the automotive industry due to their excellent cast ability, corrosion resistance, and especially their high strength to weight ratio.

There are many surface and subsurface casting defects occur during casting process. Some of these defects which are related to the molten material pouring rate are mention in this paper. Short Casting (the mold didn't fill all the way. This is usually caused by the metal solidifying before it fills the cavity. It could also be a restriction: too small a sprue, gate, not enough venting keeping the metal from going in or pouring rate is varying small). Gas defects which resulted from Gas pockets come from gas dissolving in the melt then coming out when it solidifies. This usually manifests itself as a rough surface on areas exposed to air (such as the top of the sprue, riser or ingots) or pockets of varying size in the cross-section of the metal. Gas comes from melting too long or heating too hot, 'stewing' the metal (keeping it molten longer than needed), using an unusually oxidizing or reducing flame in the furnace, getting water (or pretty much anything else that has hydrogen in it, or will burn; painted scrap for instance) in the melt, and the alignment of the Moon with the Earth and Sun. A good idea is to recycle scrap into ingots as a first step since the scrap might be wet, oily or painted and will add gas to the melt. The gas comes out in the ingots, not your casting).

2. Literature Review

A method for detecting the surface defects of cast metals was proposed by Okawa [1]. The proposed automatic inspection system consists of an industrial television camera (ITVC) and a microcomputer. A picture is taken from the ITVC in I-bit digital form and stored in the memory of the microcomputer. The computer calculates features from the picture and decides if there is any defect on the surface of the cast metal. On the other hand, Wang et. al. [2] studied the influence of casting defects on the room temperature fatigue performance of a Sr-modified A356-T6 casting alloy has been studied using un-notched polished cylindrical specimens. The numbers of cycles to failure of materials with various secondary arm spacings (SDAS) were investigated as a function of stress amplitude, stress ratio, and casting defect size. Atzori et. al. [3] studied fatigue behavior too to verify the applicability of the Atzori–Lazzarin diagram to the AA356-T6 cast Aluminum alloy. They found that the mechanical properties of AA356-T6 are strongly influenced by the metallurgical and microstructural features, and the accurate study of these parameters is the main way to improve the fatigue performance of a material. Mayer et. al. [4] worked influence of porosity on the fatigue limit of die cast magnesium and aluminum alloys. They used ultrasonic fatigue tests to show mean fatigue limits of approx. 38–50 MPa (magnesium alloys) and 75 MPa (AlSi9Cu3) in the tested casting condition. Similar results were found for low and high frequency ultrasonic tests in detecting porosity of castings. Linder et. al. [5] worked too on the influence of porosity on the fatigue life for sand and permanent mould cast aluminum.

* Corresponding author. e-mail: wisam@hu.edu.jo

Fatigue testing of sand cast and permanent mould cast specimens has been performed. They concluded that for smooth specimens an increased porosity level has been found to decrease the fatigue strength compared to notched specimen geometry where almost no influence of the pore fraction on the fatigue strength could be found. Avalle et. al. [6] produced a comparison between standard specimens and production components by casting defects and fatigue strength of a die cast aluminum alloy. Their experimental and numerical results showed that static characteristics, like tensile strength, are sensitive to defects. Nadot et. al. [7] worked on Influence of casting defects on the fatigue limit of nodular cast iron. They showed in their study that the near surface defects are much more dangerous with regard to the fatigue limit than internal defects. Webster [8] used images in a language and culture-independent expert system for diagnosing pressure die-casting defects. Experiments were conducted using the JPEG compression method. The compression and re-expansion times are very short, adding only a few seconds to the normal images disk access. The conclusion drawn was that defect catalogue and its interface to the expert systems are now essentially complete and satisfying the original purpose of providing a language and a culturally- independent interface. A study was carried out by Dharmar et. al. [9] to determine the defects in the internal microstructure of clasps of cast chromium cobalt removable partial denture frameworks. Dharmar et. al. used radiographic and metallographic evaluation of porosity defects and grain structure of cast chromium cobalt removable partial dentures. The aim of this study was to determine the defects in the internal microstructure of the clasp assemblies. The radiographic study revealed a large number of internal defects in various parts of the removable partial denture frameworks. Balaskloa et. al. [10] continued the work started by Dharmar et. al [9] and added neutron radiography in revealing the defects in an Al casting. The joint application of NR and XR revealed hidden defects located in the Al casting. Image analysis of the NR and XR images unveiled a cone-like dimensionality of the defects. The spectral density analysis of the images showed a distinctly different character for the hidden defect region of Al casting in comparison with that of the defect-free one. Ahameda et. al. [11] detected the casting defects by using UT. They worked on detecting defects in cold flakes and crack propagation in aluminum alloy die-cast plate. Their results show the ability of nondestructive detection of cold flakes by the ultrasonic microscopy. Cendrea et. al. [12] established X-ray methods for inspection of cast aluminum components by combining two approaches, a radioscopic inspection, and a photon-counting system. Cendrea et. al. [12] concluded that the radioscopic system is not well adapted to high thicknesses; defects are detected in thin parts of the cast component. Verran et. al. [13] studied the influence of the speed injection parameters in the first and second phases and of the upset pressure over the die casting parts quality, in 305 aluminum alloys is investigated. Initially, an experiment planning was performed, where several combinations of the three injection parameters were used, in order to enable the evaluation of their influence on the occurrence of foundry defects, such as porosities and cold shuts. The obtained castings sanity evaluation was performed by visual inspections and quantitative metal graph analyses, as well as by density measurements in a significant casting region, in which great quantities of porosities appear after surface machining.

Based on the previously discussed literature review, it can be clearly seen that many researchers tried to detect the casting defects using fatigue performance. The main disadvantage of this method is that it will damage the sample and it's not as accurate as needed to describe the surface and subsurface defects, because crack initiation occurs depending on shape of void or porosity. Other researchers tried to use other methods to detect the defects such as UT and RT. So, no researches studied have been in the literatures which discuss the effect of pouring rate on the formation of surface and subsurface defects.

3. Experimental Procedure

In this paper we will use ten samples of casted aluminum pieces to study the effect of pouring rate on the surface and subsurface defects. The samples should be tested without destroy them by using UT and PT.

The first step was to choose the casting piece. The key shown in Figure 1 was chosen. It has flat surface besides curved surfaces. That makes testing surface defects using PT easy. The thickness of the piece was around 2 cm. That makes using the UT possible, especially it needs the surfaces to be grinded first. The molten material was aluminum without any additives. The green sand casting process was used by making the mold and pattern. The pattern was made from wood. For each sample of the 10, a sand mold was made to exclude the effect of the mold surfaces in creating surface defects on the sample. The total volume of the mold cavity and the gates and risers was almost 46 cm3. So each time a volume of 46 cm3 of molten Al was added and the required time to finish pouring was recorded. Since the pouring speed was changed each time, the pouring rate was estimated and recorded as shown in Table 1.

After collecting the samples from the casting molds and the risers were cut, the 10 samples were tested, first using the PT and pictures describing the surface defects were takes (Figures 1-10), and then the upper surfaces of the samples were polished and tested using the UT. The results of the UT are shown in Figures 11-20.

Penetrant Testing (PT) is a method that is used to reveal surface breaking flaws by bleed out of a colored or fluorescent dye from the flaw. The technique is based on the ability of a liquid to be drawn into a "clean" surface breaking flaw by capillary action. After a period of time called the "dwell," excess surface penetrant is removed and a developer applied. Colored (contrast) penetrants require good white light while fluorescent penetrants need to be used in darkened conditions with an ultraviolet "black light". Fluorescent dyes were added to the liquid penetrant. These dyes would then fluoresce when exposed to ultraviolet light. Using this nondestructive technique, the surface defects of the casted sample can be detected.

Ultrasonic Testing (UT) is a technique for detecting internal defects through introducing high frequency sound waves into a material which are reflected back from surfaces or flaws. Reflected sound energy is displayed versus time, and inspector can visualize a cross section of the specimen showing the depth of features that reflect sound.

Table 1: Pouring rate of samples 1-10.

SAMPLE NO.	POURING TIME (S)	VOLUME (CM^3)	POURING RATE (CM^3/S)
1	13.5	46	3.4
2	7.3	46	6.3
3	5.3	46	8.7
4	4.9	46	9.4
5	3.7	46	12.6
6	3.6	46	12.7
7	3.1	46	14.9
8	2.5	46	18.6
9	2.4	46	19.2
10	1.9	46	24

Using data provided in Table 1, and using the following equation, the pouring rate could be calculated:

$$PR = V/t \quad (1)$$

Where

PR : Pouring rate (cm3/s)
V : Volume (cm3)
t : Time

4. Discussion of the Results

Figures 1-10 show the ten samples when tested using the PT. The red color indicates the surface roughness and surface defects. So, as you proceed from the first sample to the tenth sample the defects are getting more on the surface, as a result of increasing the pouring rate. Increasing the pouring rate entrapped more gases and inclusions melted in the molten material. Those inclusions and gases appear on the sample surface as the high pouring rate pressurizes them outside the material body, so they appear on the surface. Moreover, high pouring rate may mean turbulent flow which hits the mold cavity harder and results in rough surfaces.

Figure 1: Sample 1 surface defects using PT at PR = 3.4 (cm^3/s).

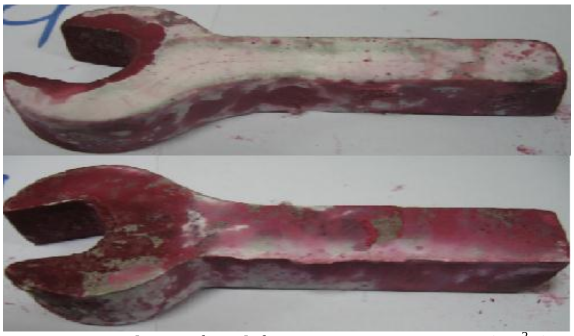

Figure 2: Sample 2 surface defects using PT at PR = 6.3 (cm^3/s).

Figure 3: Sample 3 surface defects using PT at PR = 8.7 (cm^3/s).

Figure 4: Sample 4 surface defects using PT at PR = 9.4 (cm^3/s).

Figure 5: Sample 5 surface defects using PT at PR = 12.6 (cm^3/s).

Figure 6: Sample 6 surface defects using PT at PR = 12.7 (cm^3/s).

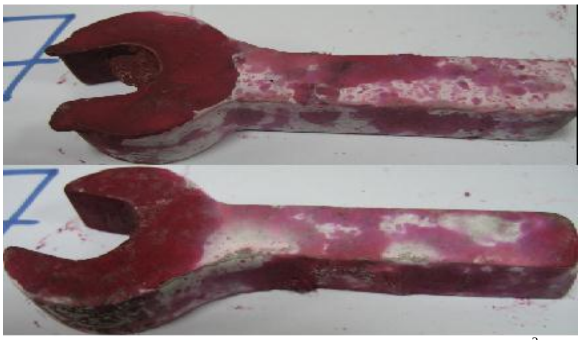

Figure 7: Sample 7 surface defects using PT at PR = 14.9 (cm^3/s).

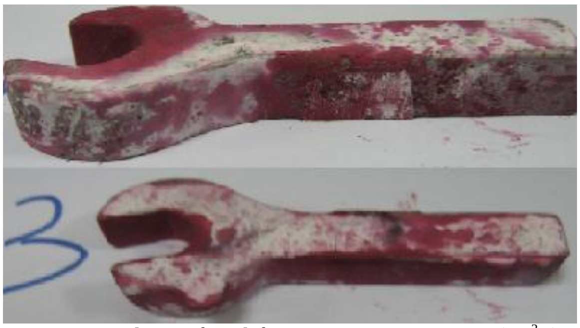

Figure 8: Sample 8 surface defects using PT at PR = 18.6 (cm^3/s).

Figure 9: Sample 9 surface defects using PT at PR = 19.2 (cm^3/s).

Figure 10: Sample 10 surface defects using PT at PR = 24 (cm^3/s).

To perform UT to investigate subsurface defects in the ten samples, they were grinded to make their surfaces smooth so that the probe moves easily on the surface to detect internal defects. The results of the UT are shown in the Figures 11-20 for the ten samples. The first highest peak and the last large peak are the boundary surfaces of the sample, while the intermediate peaks represents the defects inside the sample. As the number and the amplitude of these peaks are increasing, the internal defects are getting more. It can be easily found that as the pouring rate is getting higher, as the internal (subsurface) defects are getting less for the same reason mentioned above. High pouring rate means more pressurized molten material, that pushes the inclusions and gases outside the molten material and so they stay on the sample surface.

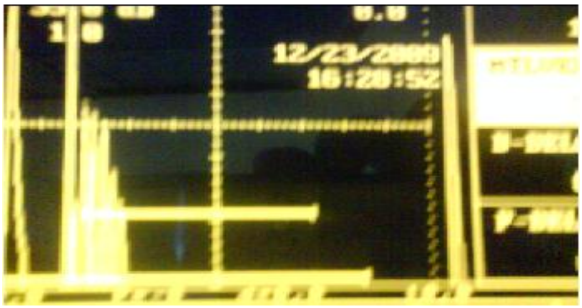

Figure 11: Sample 1 subsurface defects using UT at PR = 3.4 (cm^3/s).

Figure 12: Sample 2 subsurface defects using UT at PR = 6.3 (cm^3/s).

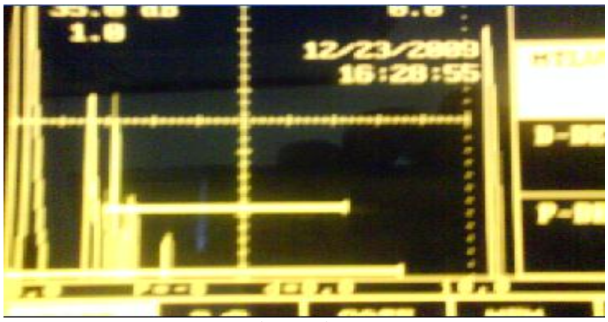

Figure 13: Sample 3 subsurface defects using UT at PR = 8.7 (cm^3/s).

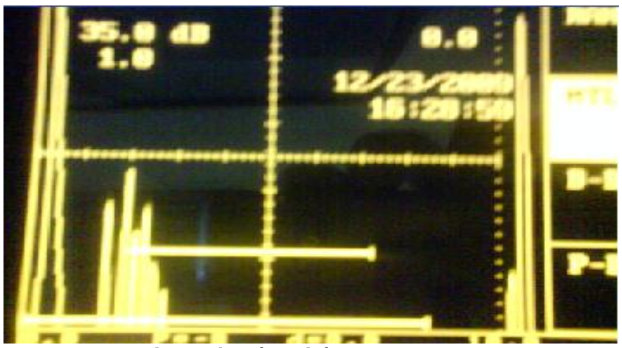

Figure 14: Sample 4 subsurface defects using UT at PR = 9.4 (cm^3/s).

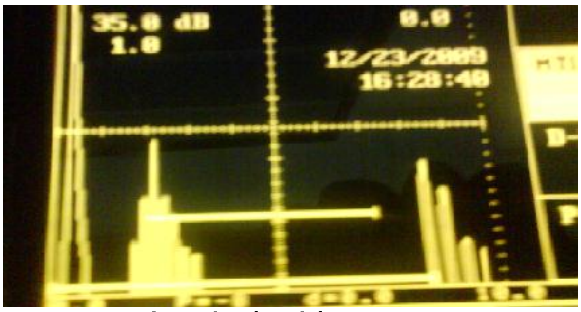

Figure 15: Sample 5 subsurface defects using UT at PR = 12.6 (cm^3/s).

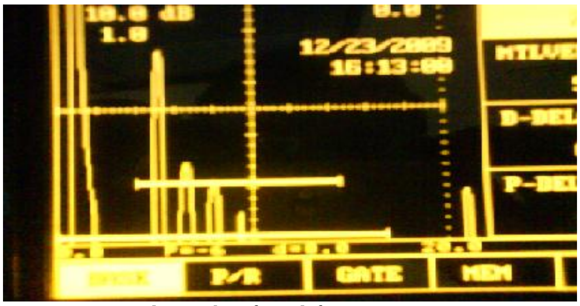

Figure 16: Sample 6 subsurface defects using UT at PR = 12.7 (cm^3/s).

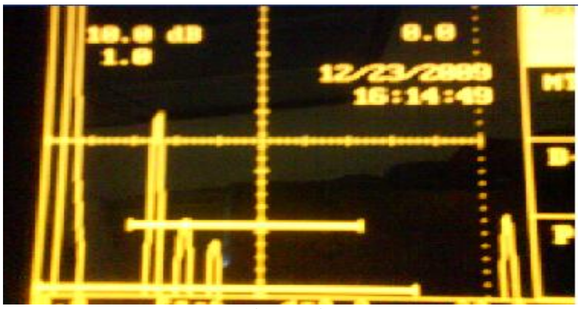

Figure 17: Sample 7 subsurface defects using UT at PR = 14.9 (cm^3/s)

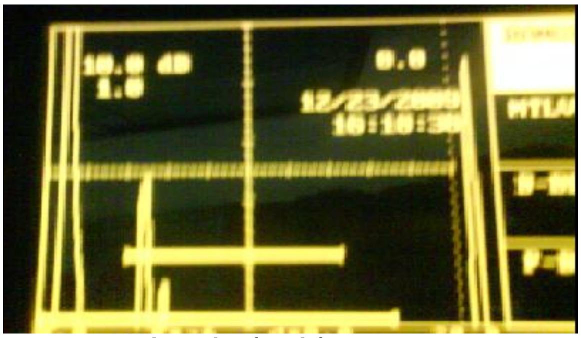

Figure 18: Sample 8 subsurface defects using UT at PR = 18.6 (cm^3/s).

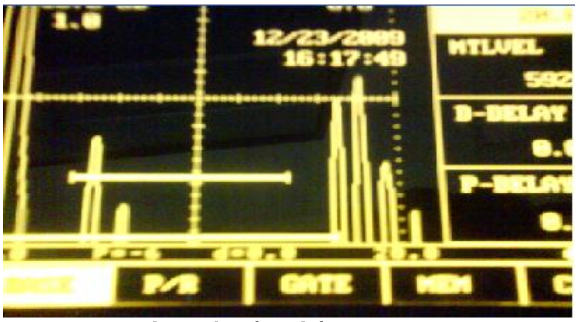

Figure 19: Sample 9 subsurface defects using UT at PR = 19.2 (cm^3/s).

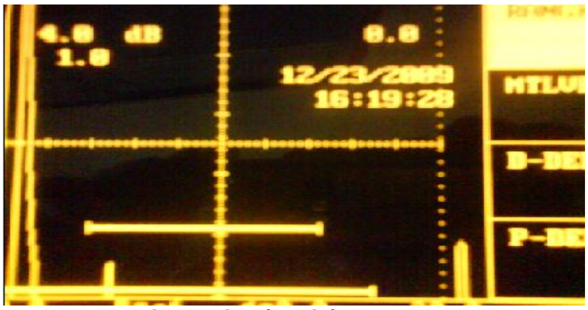

Figure 20: Sample 10 subsurface defects using UT at PR = 24 (cm^3/s).

5. Conclusions

Based on the two nondestructive testing used, the PT and the UT for the ten Al sand casted samples, the following conclusions might be drawn:

- The PT is very good tool for investigating the surface defects of casted samples with no need to damage the sample structure. Also the UT is very good tool for investigating the internal defects with no need to damage or destroy the structure of the sample.
- Both PT and UT are easy to perform and give reasonable results in case of inspecting casting samples.
- As the pouring rate of the molten material is increasing, as the surface defects of the casted sample are getting more, and the internal (subsurface) defects are getting less.
- Since the pouring rate has an opposite effect on surface and subsurface defects a compromise must be made to obtain the optimum pouring rate, and depending on the application where the surface or the internal structure is more important.

References

[1] Y. Okawa, "Automatic Inspection of the Surface Defects of Cast Metals". Computer Vision, Graphics and Image Processing, Vol. 25, 1984, 89-112.

[2] Q. Wang, D. Apelian, D. Lados, "Fatigue behavior of A356-T6 aluminum cast alloys. Part I. Effect of casting defects". Journal of Light Metals, Vol. 1, 2001, 73-84.

[3] B. Atzori, G. Meneghetti, L. Susmel, "Fatigue behaviour of AA356-T6 cast aluminium alloy weakened by cracks and notches". Engineering Fracture Mechanics, Vol. 71, 2004, 759-768.

[4] H. Mayer, M. Papakyriacou, B. Zettl, S. Stanzl-Tschegg, "Influence of porosity on the fatigue limit of die cast magnesium and aluminium alloys". International Journal of Fatigue, Vol. 25, 2003, 245–256.

[5] J. Linder, M. Axelsson, H. Nilsson, "The influence of porosity on the fatigue life for sand and permanent mould cast aluminium". International Journal of Fatigue, Vol. 28, 2006, 1752–1758.

[6] M. Avalle, G. Belingardi, M. Cavatorta, R. Doglione, "Casting defects and fatigue strength of a die cast aluminium alloy: a comparison between standard specimens and production Components". International Journal of Fatigue Vol. 24, 2002, 1-9.

[7] Y. Nadot, J. Mendez, N. Ranganathan, "Influence of casting defects on the fatigue limit of nodular cast iron". International Journal of Fatigue Vol. 26, 2004, 311–319.

[8] C. Webster, "The use of images in a language- and culture-independent expert system for diagnosing pressure die-casting defects". Journal of Materials Processing Technology, Vol. 55, 1995, 296-302.

[9] S. Dharmar, R. Rathnasamy, T. Swaminathan, "Radiographic and metallographic evaluation of porosity defects and grain structure of cast chromium cobalt removable partial dentures". The Journal of Prosthetic dentistry, Vol. 10, 1993, 369-373.

[10] M. Balaskloa, F. Korosi, Zs. Szalay, "Semi-simultaneous application of neutron and X-ray radiography in revealing the defects in an Al casting". Applied Radiation and Isotopes, Vol. 61, 2004, 511-515.

[11] Aziz Ahameda, H. Kato, K. Kageyamab, T. Komazaki, "Acoustic visualization of cold flakes and crack propagation in aluminum alloy die-cast plate". Materials Science and Engineering, Vol. 423, 2006, 313-323.

[12] E. Cendrea, V. Kaftandjianb, G. Lecomteb, K. Kjaer, "Complementarity of a photon-counting system and radioscopy for inspection of cast aluminium components". NDT&E International, Vol. 38, 2005, 239-250.

[13] G. Verran, R. Mendes, M. Rossi, "Influence of injection parameters on defects formation in die casting Al12Si1, 3Cu alloy: Experimental results and numeric simulation". Journal of Materials Processing Technology, Vol. 179, 2006, 190-195.