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Application of Non-Destructive Testing Techniques for the Assessment of Casting of AA5083 Alloy

J. Idris[*,a] *and A. Al-Bakoosh*[b]

Department of Materials Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor, Malaysia.
[a,*]*jamaliah@fkm.utm.my*, [b]*phd_bakoosh@yahoo.com*

Abstract – *Non-destructive testing (NDT) plays an important role in quality control of cast products. Typically, all cast products are inspected for external, sub-surface and internal defects. In this study, three methods of NDT; visual inspection (V.T), liquid penetrant testing (L.T), ultrasonic testing (U.T), and a combination of DT and NDT techniques were employed to assess and evaluate the metal quality of AA5083 alloy that was produced by four different casting techniques: (i) Conventional casting, (ii) in-situ melting and solidification technique (without degassing), (iii) in-situ melting and solidification techniques with degassing (argon gas was injected vertically to the surface of the metal), and (iv) in-situ melting and solidification techniques with degassing (argon gas was injected parallel to the surface of the metal). The principles of these methods are also presented, and its applications for the assessment of cast products have been highlighted. The main contribution of this paper is the application of 3D image of optical microscope technique for rough estimation of the depth of open surface defects. NDT results highlighted that the best product was produced by in-situ melting and solidification technique with degassing (argon gas injection parallel to the surface of the metal).*

Keywords: NDT, AA5083alloy, Visual inspection (V.T), Liquid penetrant testing (L.T), Ultrasonic testing (U.T), Casting

1.0 INTRODUCTION

NDT is not just a method for rejection or acceptance of a material, but it is also used to confirm the material is either good or not [1]. Non-destructive inspection is a powerful tool for improving product quality, reducing costs and maintaining quality levels [2]. Six main NDT methods are: visual inspection (V.T), liquid penetrant testing (L.T), magnetic particle testing (M.T), electromagnetic or eddy current testing (E.T), radiography (R.T), and ultrasonic testing (U.T). In addition, there are many NDT techniques that have been developed, with more than 50 techniques have been developed for different purposes [3]. The detection of material's defects by using several physical probing techniques is known as non-destructive testing (NDT) approach [4].

NDT techniques can be used for a variety of purposes, such as:

- To detect unwanted discontinuities and separations in a material (flaws).
- To assess the structure of a component (microstructure and matrix structure).

- For metrology and dimensional purposes such as thickness measurement, checking of displacement and alignment [1].

The capability to test cast products by employing NDT techniques depends upon the material type, surface roughness, and type of defects to be detected. All these factors must be considered with accuracy to get adequate results [5]. Cast products suffer heavily from various defects. The origin of these defects is due to various sources such as material used, design of the mold, shape of the part and also other process parameters (melting, pouring, and solidification). Casting defects can be classified into three major groups: (I) void-type defects such as porosity, microporosity and gas holes, (II) inclusions such as sand, slag and dense inclusions, and (III) crack type defects like shrinkage (micro and spongy), hot tears and cracks. Most of the casting defects types can be detected with a simple visual inspection by naked eyes [6]. The inspection methods of casting can be divided into destructive, non-destructive categories or a combination of them. Destructive methods are generally related to sawing and breaking off parts of the castings at places where internal defects are suspected. No single NDT technique can provide a complete solution for casting quality inspection. In many cases, NDT methods or combinations of NDT and DT are usually used to determine the desired inspection [7]. For visual inspection of cast products, the inspector must be familiar with all types of casting defects, and also have skills of inspection and verification [8].

2.0 PRINCIPLES OF NDT USED

The principles of NDT techniques for V.T, L.T and U.T that have been applied in this research are briefly described as follows:

2.1 Visual Inspection (V.T)

Visual inspection is the original method of NDT and should not be neglected when implementing NDT techniques. In most cases, this method is followed by more sophisticated NDT methods [9]. There is a big difference by looking at the object and seeing it through an expert's eye. Visual inspection involves both direct and indirect methods. Direct method is where the material is inspected directly by the naked eye without additional visual aids. In the case of indirect method, it involves the use of various magnification devices such as optical microscopes, mini camera and others [8]. This test needs an inspector with adequate vision, experience and knowledge related to the sample to be tested to allow the inspector to make the correct assessment regarding the status of the inspected sample [10].

2.2 Liquid Penetrant Test (L.T)

Liquid penetrant testing (L.T) is used to detect surface discontinuity in both ferrous and non-ferrous castings [7, 11]. The principle of this method is capillary action, which is the ability of a liquid or dye to travel to or be drawn onto a surface opening. L.T has the capability to detect surface defects with higher clarity than V.T and makes defects easier to see. The limitation of this test is that the discontinuity must be open to the inspection surface [4]. Furthermore, this method cannot be used to detect sub-surface discontinuities. Liquid penetrant (L.T) method is performed as follows:

- The surface of the material inspected should be cleaned with a specific cleaner and then dried.

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- A liquid penetrant is sprayed onto the surface of the material according to the standard.
- Excess liquid is removed from the surface by rinsing with acetone.
- A developer is applied over the surface of the material to reveal liquid penetrant trapped in defects by chemical reaction.
- Inspection of the material is performed, and defects are located.

2.3 Ultrasonic Test (U.T)

The ultrasonic testing (U.T) technique uses ultrasonic waves for sub-surface and internal defect's detection and sizing in both ferrous and non-ferrous castings. The method uses reflection and transmission of high-frequency sound waves. The most suitable frequency is the range from 5 to 10 MHz for the inspection of Al alloys castings with surface roughness (Ra) values varying between 50 µm and 100 µm [12]. The major limitation of the U.T technique is the sensitivity of ultrasonic inspection to surface roughness of the castings [12, 13, 14]. Sound waves travel through the material and then reflected at the interface, with some energy loss. The reflected beam is displayed and then analyzed to define the presence and location of flaws or discontinuities. Fig. 1 shows the typical ultrasonic waves indications of four types of flaws found in castings [15]. There are a number of factors that cause defects in the casting products, which depend on the quality of raw materials and its respective process [16].

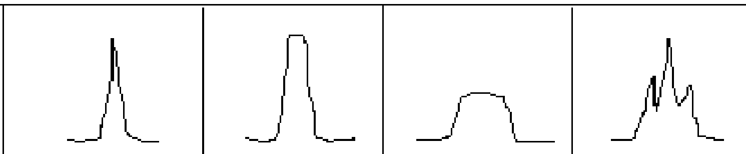
Signal form				
Description Indication	Sharp echo Cracks	Not sharp echo Slag	Broad echo Sand inclusion or blow holes	Multiple shrinkage

Figure 1: Typical ultrasonic indications of four types of flaws found in castings [15].

3.0 METHODOLOGY

3.1 Material Fabrication

AA5083 aluminium alloy was fabricated via four different casting techniques using an induction furnace as shown in Fig. 2. The first technique was conventional casting (melting-pouring-solidification). The second technique was in-situ melting and solidification technique, whereas the third technique was in-situ melting and solidification technique with degassing (injection of argon gas vertical to the surface of the metal). Lastly, the fourth technique was in-situ melting and solidification technique with degassing (injection of argon gas parallel to the surface of the metal).

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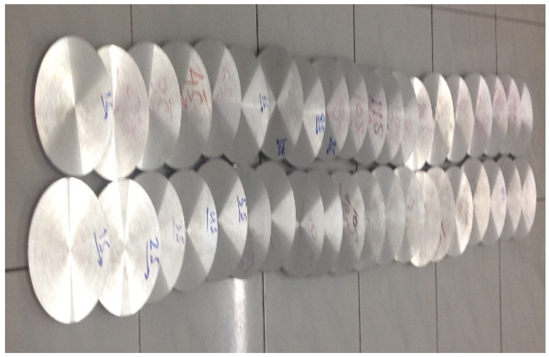

Figure 2: The ingot shape of AA5083 aluminium alloy.

3.2 Inspection Methodology

Three NDT techniques (V.T, L.T, U.T) and also a combination of DT and NDT were carried out for testing cast material (AA5083 alloy) that was produced by four different casting techniques to evaluate casting techniques quality. All NDT were performed according to international specifications in order to assess and evaluate the metal quality of AA5083 alloy produced by four different casting techniques [17, 18, 19].

3.2.1 Visual Inspection (V.T)

V.T techniques, which were direct method (naked eye) and indirect method (optical microscope), were carried out to assess the surface of AA5083 alloy (according to ISO 10049 - aluminium alloy casting) for 100% inspection in the case of direct method, but for the indirect method, random samples were selected.

3.2.2 Liquid Penetrant Testing (L.T)

The L.T was performed according to ISO 9916 - aluminium alloy casting for random samples of AA5083 alloy to assess the surface of AA5083 alloys produced using four different techniques.

3.2.3 Ultrasonic Test (U.T)

This technique was carried out to assess internal defects (according to ASTM specification B548-76) for random samples.

3.2.4 Combination of DT and NDT Techniques

The samples were sawed at places where void or internal defects were suspected. The selection of cutting places is as shown in Fig. 4.

3.2.5 Metallurgical Inspection

An optical microscope was used to obtain more detail about porosity; to confirm its existence, nature, size, and distribution.

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4.0 RESULTS AND DISCUSSION

All observations and tests results are based on factual records. For comparison, four casting techniques that were used to produce AA5083 alloys were compared to determine the alloy with the best quality. Multiple NDT methods were applied for the determination of quality of AA5083 alloy castings, where three NDT techniques (V.T, L.T and U.T) were performed. Selecting suitable NDT technique or combination of DT and NDT techniques requires deep understanding of the case to be solved. A feature common to most NDT is that they provide more information about the properties and structure of the material tested and then can be easily interpreted. The samples were prepared for inspection. Fig. 2 shows quantitative and qualitative assessment of the macro cleanliness of AA5083 alloys.

4.1 Visual Inspection (V.T)

Through visual inspection, all types of defects associated with the casting process were considered as well, such as porosity, laminations, inclusion, micro-cracks, and other, in order to ensure that cast products are free from defects or not, and then rejection or acceptance of the samples was decided. All the samples were free of burrs, inclusions, cracks, scorches and signs of overheating. However, the discontinuity in the form of porosity was clearly noticed on the surfaces of the samples that were produced by the first or second techniques as shown in Fig.3a, while no porosity defect was observed on the surfaces of the samples fabricated by the third and fourth techniques as shown in Fig. 3b.

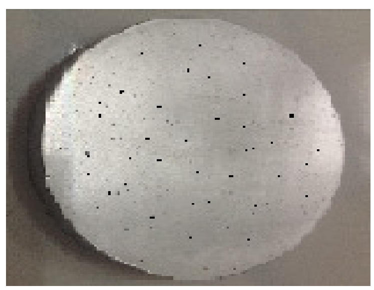
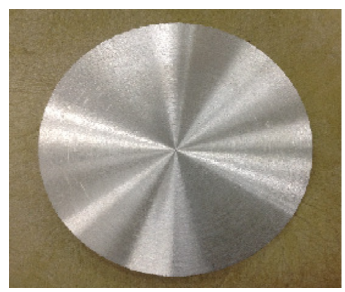
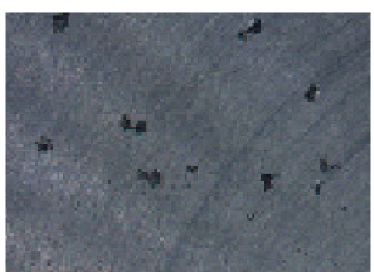
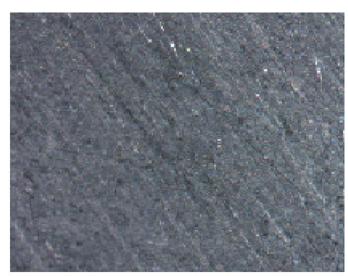
Method	Principle	Result	
		(Non-Conformity) / Rejected	(Conformity) /Accepted
V.T	Direct Method (Naked eye)		
	Indirect Method (Optical Microscope)		
		Fig. 3a	Fig. 3b

Figure 3: V.T results of AA5083 alloys; (a) sample prepared by the second fabrication technique and (b) sample prepared by the fourth fabrication technique.

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4.2 Liquid Penetrant Testing (L.T)

The results of this test were similar to the visual inspection. Fig. 4 shows photographic surface image of AA5083 aluminium alloys. Fig. 4a shows very clear contrast and intensive macroporosities on the surface of AA5083 alloy sample that was prepared by the second fabrication technique. Fig. 4b shows free porosities surface of AA5083 alloy sample that was prepared by the fourth fabrication technique. L.T technique showed microporosities that could not be investigated by V.T technique as shown in Fig. 3a. This confirms that the ability of L.T technique to detect macroporosity and its morphology was better than V.T technique.

4.3 Ultrasonic Test (U.T)

Before starting the ultrasonic testing, calibrations were carried out, and the results obtained from the UT technique discovered sub-surface and internal discontinuity in the samples that were prepared by the third fabrication method. It was not detected by the V.I and L.T techniques, where no discontinuity was discovered in the samples that were prepared by the forth fabrication method. Fig. 5 shows the schematic diagram of UT detection of AA5083 alloys using normal probe ((a) porosity detected, (b) no discontinuity detected). By carrying out the comparison between the wave's shape appeared on the screen of the UT instrument with the wave's shape of Fig.1, the typical ultrasonic indications of four types flaws found in castings were shown [15]. Based on that comparison, the defect can be classified as microporosity defect.

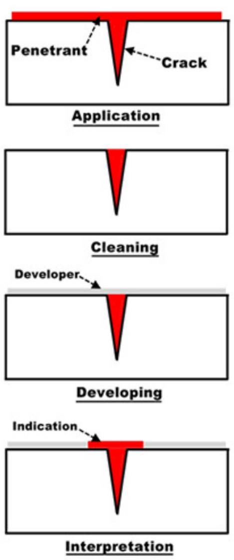
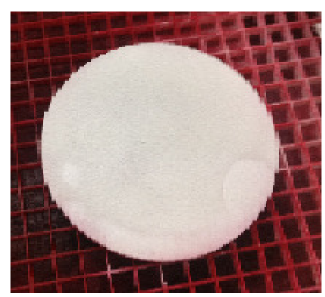
<table>
<tr><th rowspan="2">Method</th><th rowspan="2">Principle</th><th colspan="2">Result</th></tr>
<tr><th>(Non-Conformity)/ Rejected</th><th>(Conformity)/ Accepted</th></tr>
<tr><td>L.T</td><td>
</td><td>
(4a)
The L.T result of AA5083 alloy sample prepared by the second fabrication technique.</td><td>
(4b)
The L.T result of AA5083 alloy sample prepared by the fourth fabrication technique.</td></tr>
</table>

Figure 4: Photographic images of the surface of AA5083 alloys showing (a) micro-porosities and (b) no porosities.

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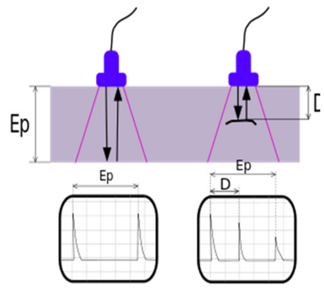
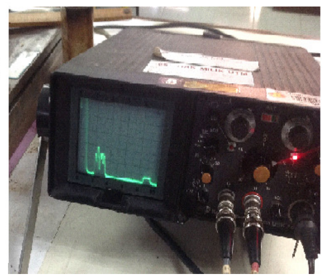
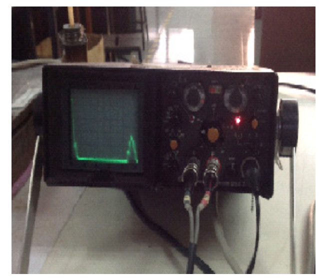
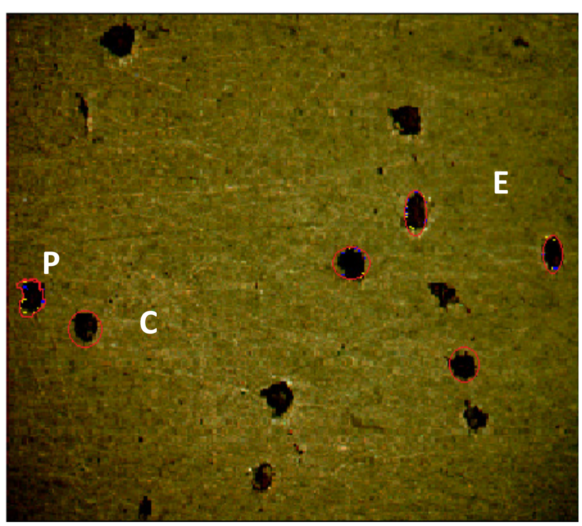
Method	Principle	Result	
		(Non-Conformity)/ Rejected	(Conformity)/ Accepted
U.T		 (a) The U.T result of AA5083 alloy sample prepared by the third fabrication technique (Porosity detected)	 (b) The U.T result of AA5083 alloy sample prepared by the fourth fabrication technique (No defect detected)

Figure 5: Schematic diagram of UT detection of AA5083 alloys using normal probe.

4.4 Metallurgical Inspection

Optical microscope image displayed clear heterogeneous microporosities in the form of dark spots as shown in Fig. 6.



C= Circle; E= Ellipse; P= Polygon

Figure 6: Distribution and shapes of porosities.

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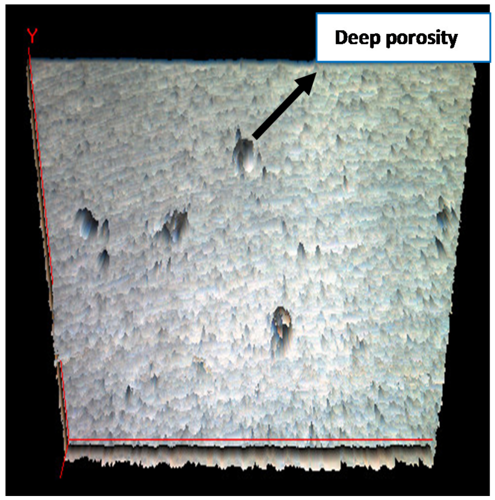


Figure 7: 3D image of optical microscope for AA5083 alloy.

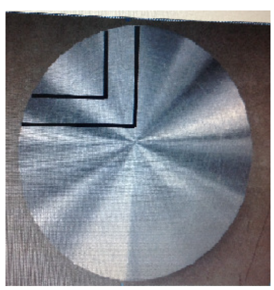
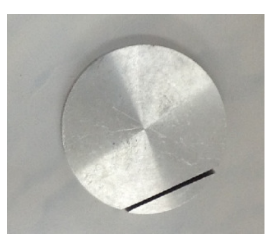
Method	DT (the surface of the path of the cutting was inspected by visual inspection and liquid penetrant)	NDT (visual inspection) + (liquid penetrant)
Combination of DT & NDT		
		

Figure 8: Combination of DT and NDT for AA5083 alloys.

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These porosities have different sizes (0.31-0.70 mm) and different shapes (the shape appeared as circle, ellipse and polygon). Also, the distribution was not uniform as clusters were formed. Accordingly, it is difficult to predict the behavior of AA5083 alloys that were produced by the first, second and third techniques. NDT reliability and efficiency have been improved by employing computer-aided system and artificial intelligent technique. 3D image of optical microscope was used to estimate roughly the depth of the open surface porosities. Meanwhile, the depth of most of the detected porosities was not clear, as shown in Fig. 7.

4.5 Integrity of DT and NDT Tests for Subsurface Defects and Internal Defects

For the combination of DT and NDT test on AA5083 alloy ingot, as shown in Fig. 8, DT was related to sawing of parts of casting (ingot) at different places where the internal defects were suspected. However, the cuts maybe miss the indentation of internal defects, especially for micro-scale defects. Hence, this explains the integrity of the combination of DT and NDT that leads to less reliable results than NDT.

5.0 CONCLUSION

According to the obtained results, the conclusion of this paper can be summarized as follows:

The visual test, in many cases, can be relied upon in the decision-making (non-conformity) without the need for other tests:

- Liquid penetrant technique can give a clear picture on the distribution of the porosities on the surface.
- 3D image of optical microscope can be used for rough estimation of the depth of open surface porosities.
- Successful of use NDT on foundry depends on the skills of user, tools and machine conditions, such as the calibration of machine and the selection of a suitable method for inspection.
- For UT, the surface condition and shape of the samples are very important, as smoother surface and less complex shape can generally produce more satisfactory results.
- Integrity of DT and NDT leads to less reliable results than NDT.

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