National And International Standards On Ultrasonic Examination of Steel Castings Used In Bucket Wheel Excavators – A Comparison Study

E.Sivasubramani
L&T Metallurgical and Material Handling, Chennai, India
esivaa@gmail.com

Abstract

This study’s principal objective is to compare national and international standards on ultrasonic testing of steel castings used in bucket wheel excavators of open cast coal mines. Since these moving equipment are rugged in construction and weighing more than 2000 tonnes, the casting soundness used in primary and secondary structures play an important role on the reliability and machine availability for coal and overburden excavation, ultimately uninterrupted supply to the thermal power plant.

Many requirements of ultrasonic testing standards including transducer frequency, transducer diameter, backwall echo attenuation, reference level amplitude, severity level, indication size, indication length, characteristics of indication, diameter of equivalent circular reflector will be studied.

The correlation between the design requirements of casting soundness (possibly derived from fracture mechanics) and the things achievable in real world conventional ultrasonic examination will be studied.

Various acceptance levels will be studied and compared with the design requirements. If the specific design requirements are not available, the contract documents and practical feasibility will be studied.

The ultimate aim is to compare the national and international standards to have a better understanding on the capability, feasibility, and efficacy with regard to the requirements of the standards.

Introduction

In bucket wheel excavators (BWE) a wheel is equipped with buckets along its circumference and is moved sideways into an excavation face while it rotates about its own axis, a circular cut will be made in the excavation of material. If the bucket wheel so mounted that it can be moved in a particular area, it can be used for removal of earth as is required by earth moving machines. In order to make the BWE independent in its working area, it is made mobile [1]. It weighs around 2000 tonne.

Castings namely drive tumbler, return tumbler, bottom travel wheel, top travel wheel, bearing housing measuring maximum 1450 mm diameter and 500 mm thickness are used in manufacturing BWE. These are highly stressed castings and require superior internal soundness. The material is GS42CrMo4V as per DIN 17205: 1992 – Quenched and tempered steel castings for general applications.

Although there are many international and national standards published on ultrasonic testing of steel castings, bucket wheel excavator manufacturers traditionally prefer DIN 1690 Part 2: 1998 regardless of its revision in to EN 12680-1. This paper analyzes various aspects of the following standards.
1. DIN 1690 Part 2: 1998 - Technical delivery conditions for castings made of metallic materials – Steel castings; classifications into severity levels on the basis of non-destructive testing hereinafter referred to be as DIN.

2. ASTM A609/A609M-12 - Standard practice for castings, carbon, low-alloy and martensitic stainless steel, ultrasonic examination thereof. Hereinafter referred to be as ASTM.

3. AS 2574 – 2000 – Non-destructive testing – Ultrasonic testing of ferritic steel casting hereinafter referred to be as AS.

4. IS 9565:1995 – Acceptance standards for ultrasonic inspection of steel castings – Specification hereinafter referred to be as IS.

**Scope of the standards**

All the discussed standards deal with the ultrasonic inspection of steel castings while ASTM particularly includes martensitic stainless steel also. While AS does not apply for austenitic steel IS states ultrasonic testing of austenitic steel may not ordinarily be feasible. DIN conditions clearly that in case of austenitic materials, only radiographic inspection shall be carried out thus prohibits the use of ultrasonic testing on austenitic steel castings. AS limits the thickness of castings as 15 mm, while all other standards remain silent on thickness limitation. Practically ultrasonic testing of castings of less than 10 mm thick using conventional testing techniques has its own demerits; it does not find a place in the scope of many standards. DIN stipulates the upper thickness limitation as 600 mm.

**Qualification of testing personnel**

All of the standards accept personnel qualified to relevant national or international standards. The ultrasonic testing shall be conducted by personnel qualified at least to Level I and evaluated by at least Level II.

**Equipment and Transducer**

Pulse-echo equipment which is capable of operating over a frequency range of 0.5 to 5 MHz with an A scan representation is generally acceptable in all of the standards when DIN stipulates the slight increase in the upper frequency as 6 MHz.

Compression wave transducer of 13 mm to 25 mm major dimension is generally accepted by all. IS specifies the size of 25 mm diameter or 25 mm square while allowing higher or lower frequencies depending upon factors such as grain structure of the castings, thickness of the castings and acceptable size of the discontinuities. Shear wave and double element probes are allowed in all the standards.

Horizontal and vertical linearity are more or less on with similar tolerance levels. Resolution requirements are a bit stringent in IS and has to be demonstrated through calibration block specified and is not frequency dependent. Requirements of resolution requirements by specifying maximum separation of adjacent reflectors are specified in AS. Resolution requirements are not detailed in ASTM and DIN specifies requirements of resolution.

Scanning rate shall not exceed 150 mm/s in all of the standards.

**Casting conditions**

ASTM requires castings receive at least an austenizing treatment and shall have a surface free of material that will interfere with the ultrasonic examination. Roughness values are not specifically mentioned in ASTM while IS specifies better than 12.5 µm and requirement does not exceed 6.3 µm.
for AS. DIN specifies the surface finish corresponds to the reference specimen 4S1 (in case of blasted surface) or 4S2 (in case of ground surface) of the standards series CTIF-341-Ø2.

**Zonal division of castings**

The zonal division of castings is not envisaged in ASTM as defined in figure 1. All other standards divide the casting into zones and acceptance characteristics are based on the zones. A discontinuity which is larger in size and distribution is acceptable in mid zone rather than outer zone. This might be based on the solidification characteristics of steel castings. Generally, the surface discontinuities of near surface discontinuities are more detrimental than the one which lie middle of the surfaces. This might be the reason for the formulation of the acceptance standards.

![Figure 1: Division of casting wall into zones](image)

**Individual and accumulated area of defects**

Individual and accumulated areas of defects are not envisaged in ASTM and AS as depicted in figure 2. An individual defect is one which is separated from an adjoining defect by a distance not less than the maximum dimension.

An individual defect’ is one which is separated from an adjoining defect by a distance not less than the maximum dimension of either of the defects. The “individual area of defect” refers to the area of such an individual defect as delineated on the surface of the casting. \( F_1, F_2 \) and \( F_3 \) are the individual areas of defect and the accumulated area of defects would be the total of the individual areas of defect, that is, the sum of \( F_1 + F_2 + F_3 \), if the distance between the defects were \( < L_1 < L_2 \), and \( < L_3 \). The dimensions \( L \) and \( B \) refer to the length and breadth of the defective area delineated on the surface of the casting. This is obtained by connecting the marks made during the scanning on locations where the reference level was exceeded. Marks are coincident with the midpoints of the transducers.
While testing large cross-sections, a realistic evaluation of the discontinuity shall be achieved by considering the beam spread and geometry.

In the case of an isolated (point-like) indication, the area of defect is taken as the area of the transducer. However, smaller diameter probes may be used for determining the actual size of the defect.

Individual area and total area calculations are more or less same in IS and DIN. Weld repairs shall be inspected and assessed for acceptability in accordance with the requirements stated in enquiry or order, taking into account the area and zone of the casting in which the weld repair is located. Weld repairs and its acceptance in mentioned in AS and IS while other standards remain silent on this issue.

Equivalent Flaw Size and Flat Bottom Hole

Equivalent flaw size, flat bottom hole, length and area of discontinuity and loss in back reflection remain as acceptance norms for most of the standards. Distance amplitude correction curve (DAC) is used for FBH and DGS (Distance Gain Size) is used for Equivalent flaw size. ASTM does not specify equivalent flaw size but specifies flat bottom hole. Generally for casting applications, American standards do not endorse DGS as a lot of variable like attenuation and beam spread have to be taken into account while testing using DGS. American standards usually, in most of the occasions, except for forgings, do not accept DGS but depends on taking echo references from materials of same acoustic characteristics and same material with similar heat treated conditions.

ASTM includes procedure using time corrected gain (TCG) which no other standards specify. Practically, the exercise of using TCS is much more beneficial and nowadays most of the modern ultrasonic flaw detectors have in built TCG facility. In TCG equal dimension reflectors give equal amplitude responses for all sound path distances being ultrasonically scanned [6]. When using a DAC, the signals at greater distances are a smaller percentage of the FSH than those nearer the probe. The use of TCG means that all the signals requiring evaluation are at the same % FSH on the probe.
flaw detector screen, no matter at what distance they appear [7]. This phenomenon is depicted in figure 3.

There are three levels of acceptance as per equivalent flaw size or FBH in AS which are 6 mm diameter, 8 mm diameter and 10 mm diameter for high stresses castings, intermediately stressed castings and low stressed casting respectively. IS gives equivalent flaw size acceptance ranks from 3 mm to 5 mm depending on levels of acceptance and also in accordance with the zonal classification. DIN specifies 3 mm to 8 mm equivalent flaw sizes for acceptance based on zones and severity levels. ASTM specifies only 6.4 mm as flat bottom hole and the levels vary in accordance with the length and area of discontinuity distribution.

**Loss of back reflection**

Sound shadows reduce the amount of energy reflected from the back surface by reducing the effective area of the sound beam. The back reflection is not reduced in direct proportion to the percentage of the original sound beam intercepted by the flaw; the exact proportion varies widely. This effect is termed loss of back reflection, regardless of whether the back-surface signal echo is lost completely or merely reduced in amplitude. A loss of back reflection can occur even if no flaw indication appears on the A-scan display [8]

While testing, transducer has to be placed on many areas of the casting where it requires the least gain (dB) for back wall indication for setting it at 100% Screen Height. Any loss afterwards while scanning other areas is considered to be the loss in loss in back reflection.

Loss of back reflection allowed varies from 50% to 90% for DIN and AS depending on severity level of acceptance. IS specifies 75% to 90% while ASTM specifies a single acceptance value of maximum 75% loss in back reflection.

**Acceptance Norms**

Designers of Bucket wheel excavators specify Severity Level 1 as per DIN which is the most stringent available in all of the standards discussed. It specifies a maximum 3 mm equivalent flaw
size and maximum 50% loss in back reflection. It requires specialized gating system and runner, riser geometry during casting stage for achieving severity level 1. Three reflectors are allowed in a square decimeter tested area and all the reflectors should have no measurable extension. A graph showing sound beam path in X axis and sound beam diameter (-6dB) in Y axis is provided in Steel and Iron Test Sheet 1922 : 1985 for distinguishing between discontinuities with or without measurable dimensions. [9]

**Conclusion**

In this comparison study, it is established that DIN 1690 Part 2: 1988 with severity level 1 is the standard which is proved to be the stringent ultrasonic testing standard among the standards discussed because the castings used in bucket wheel excavators experience high hertzian pressure during operation.

**References**


[2] DIN 1690 Part 2: 1998 - Technical delivery conditions for castings made of metallic materials – Steel castings; classifications into severity levels on the basis of non-destructive testing


