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Classification and Rating of Inclusions in Steel Using an Image Analysis Software

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ABSTRACT

Inclusions play an important role in the performance of steel products. In this respect, they should be accurately characterized in steels. Developing computer technology and softwares have been allowed to evaluate the inclusion content of a steel products by classifying and rating numerous inclusions in a large number of fields through optical microscope. However, due to the difficulties encountered in classification, it still needs experienced operators' intervention, and advanced tools like SEM-EDS for accurate results.

Keywords: Steel; Inclusion; Inclusion rating; Image analysis; Metallography

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INTRODUCTION

Inclusions are non-metallic particles embedded in steel matrix. The particles usually are compounds such as oxides, sulphides, and silicates, but may be any substance insoluble in the matrix [1]. Sims [2] classified nonmetallic inclusions based on their origin as endogenous and exogenous. The endogenous inclusions are formed by the reactions in liquid metal in steelmaking process and their formation is dictated either by additions to the liquid metal or by changes in solubility during the solidification process. Oxides and sulphides are examples of endogenous non-metallic inclusions in steels. The exogenous inclusions in steels, on the other hand, occur as a result of trapping of slag, refractories, and oxidized metal that the liquid metal comes in contact with during the melting and casting process [2,3].

While inclusions are advantageous for certain applications such as machining and oxide dispersion strengthened steel alloys, under uncontrolled conditions they can be deleterious to the performance of a steel product [4]. Their origin, type, size, shape, number, and distribution may influence almost all properties of a steel such as formability, machinability, weldability, fatigue, fracture, creep, corrosion, and toughness [4,5]. Therefore, inclusions should be identified, classified, and rated prior to manufacturing processes of a steel product. Various techniques are available to monitor and characterize the inclusion content of a steel. Microscopic technique based on viewing a metallographically prepared sample through an optical microscope is still very valuable and prevailing one among all known methods. In this method, the inclusions in a polished sample are observed through an optical microscope and classified and rated according to a standard method. Standard reference charts depicting a series of typical inclusion configurations (size, type, and number) in those standards have been created for direct comparison with the microscopic field of view [6]. Therefore, rating practically can be done in comparison with the standard charts such as ASTM E45 [7]. In these charts inclusions are assigned to a category based on similarities in morphology, i.e. by shape, size, concentration, and distribution.

Inclusions are classified into four categories called as type based on their morphology. Each of them is classified into two subcategories based on their width or diameter. Although the categories contain chemical names that imply knowledge of their chemical content, the ratings are strictly based on morphology. In ASTM E45, the four categories, or types, are partitioned into severity levels based on the number or the length of the particles present in a 0.50 mm^2 field of view (Figure 1).

A-type and C-type inclusions are very similar in size and shape. Therefore, they are distinguished based on their color when viewed under the brightfield illumination of an optical microscope, A-type as light gray and C-type C as black. B-type inclusions consist of at least three of round or angular oxide particles with aspect ratios less than 2 that are aligned nearly parallel to the deformation axis. D-type inclusions are globular in shape.

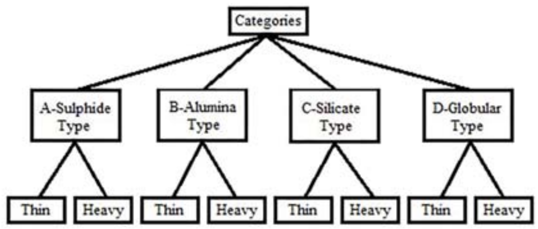

Figure 1. Classification of inclusions according to ASTM E45 [7].

As mentioned above, a common method for the analysis of inclusions is the comparison of the microscopic fields with reference charts. Manual method is rather time consuming, thus restricted with limited fields, thanks to the image analysis softwares a large number of inclusions in numerous fields can be rapidly classified and rated according to their morphological differences through optical microscope [8]. However, due to the difficulties in distinguishing sulphide, silicate, and oxide inclusions it still needs experienced operators' intervention, and advanced tools like scanning electron microscope (SEM) equipped with energy dispersive spectrometry (EDS) analysis for accurate results.

MATERIAL AND METHODS

A sample was taken from a hot rolled S275 JRC steel sheet in 3.5 mm thickness, which is suitable for wheel manufacturing. In wheel steels, elongated inclusions have a deleterious effect on the performance of rim forming and electrical resistance welding, therefore, the sulphide and alumina type inclusions are principally modified by a Ca-Si treatment in steelmaking process. During the Ca-Si treatment, alumina/silicate type inclusions are converted to molten calcium aluminates/silicates, which are globular in shape because of the surface tension effect at liquid stage, and thus become harmless. The change in inclusion composition and shape is known as the inclusion morphology control. Following steelmaking process, cast and solidified metal is hot rolled into final sheet thickness.

The sample was mounted in bakalite so as to expose the cross-sections parallel to rolling direction, ground with 180, 240, 320, 400, 600, and 1000 grit SiC papers, and polished with 9, 6, 3, and 1 μm diamond pastes on napless polishing cloths. Subsequently it was washed, rinsed with ethyl alcohol, and dried with blown air.

Inclusion content of the sample was viewed by Nikon Epiphot 200 optical microscope (OM) at 100x magnification, and the detected inclusions were analyzed by Jeol 5600 JSM scanning electron microscope (SEM) equipped with Oxford energy dispersive spectroscope (EDS). Clemex Inclusion Rating (CIR) software integrated with the optical microscope was used to discriminate, categorize, measure and rate the inclusions found in the sample.

The total analysis area was 376.48 mm^2. Inclusions were classified into four types and categorized into thin and heavy series as shown in Figure 1. The results were expressed according to ASTM E45 Method A [7].

RESULTS AND DISCUSSION

The first step for the automated inclusion rating system is to adjust the light of optical microscope and to verify the threshold. According to the gray level, the threshold defines whether it is a sulfide or an oxide (Figure 2).

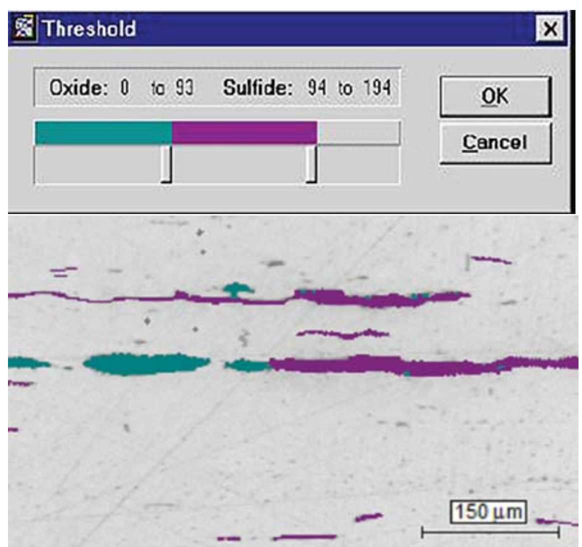

Figure 2. According to defined gray level, inclusions are detected as a sulfide or an oxide.

During thresholding, difficulties were encountered in discriminating the thin sulphide, silicate, and oxide type inclusions since thin B and D-type inclusions were often confused with thin A-type inclusions (Figure 3a-c).

SEM-EDS analysis was performed on the selected inclusions to prevent any confusion. In this way, many thin inclusions previously identified as B-type based on the morphological appearance through optical microscope were corrected as A-type with the aid of Mn and S peaks (constituents of MnS) in the SEM-EDS spectrum (Figure 3b).

Additionally, the inclusions previously identified as globular oxides were revealed as modified Ca-Al-O spinel inclusions based on their SEM-EDS analysis (Figure 3d).

Following the results of SEM-EDS analysis, threshold levels in Clemex CIR software were redefined and the incorrectly identified inclusions were converted to true ones. As shown in Figure 4, the squares of a specific color indicate the worst fields (thin and heavy) for each category.

microscopic fields, whereby large amount of steel products could be analyzed in terms of inclusion content. However, due to the difficulties encountered in classification it still needs experienced operators' intervention, and advanced tools like SEM-EDS for accurate results.

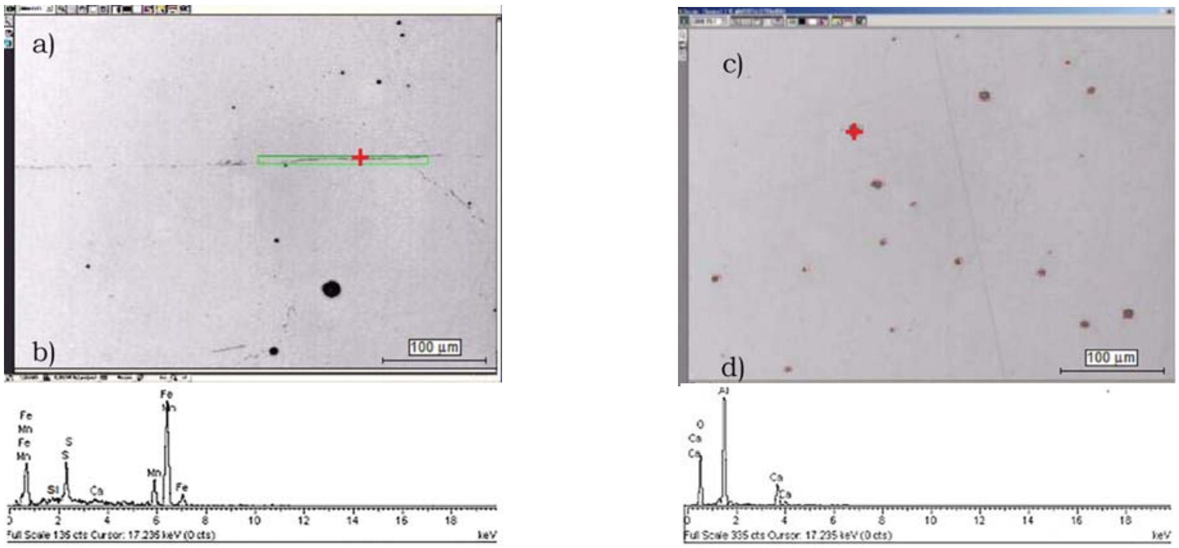

Figure 3 (a) elongated and (c) globular inclusions through optical microscope, and (b) and (d) their SEM-EDS analysis at red crosses "+" in micrographs respectively.

To validate the results, the detected inclusions in the worst fields were reviewed. If a dust residue or polishing scratch remaining from the sample preparation process was detected as an inclusion, it was removed from the results. The results were expressed according to ASTM E45 Method A (Table 1).

CONCLUSION

It is well established that inclusions play an important role in the performance of steel products, depending on their type, size, shape, and distribution. In this respect, they should be accurately characterized in steels. Thanks to rapidly developing computer software technology, it allows inclusions to be evaluated according to their type, size, shape, and distribution in a steel by classifying and rating of numerous inclusions in a large number of

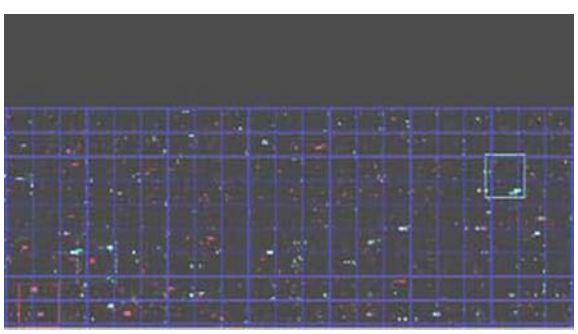

Figure 4. Total analysis area.

Table 1. Clemex CIR report

Sample ID	Width (mm)	Height (mm)	Area (mm^2)	Calibration	Magnification
Sample 1	14.71	3.02	67.76	0.383	200x

Heat 1 – ASTM E45-97A

Sample ID	Thin	Heavy	Thin	Heavy	Thin	Heavy	Thin	Heavy
Sample 1	2.00	0.50	0.75	0.00	0.00	0.00	2.25	0.75

REFERENCES

1. Metallography and Microstructure, Metals Handbook, Vol. 9, Ninth Ed., ASM (1985) p. 9.
2. Sims, C. E. Transactions of the Metallurgical Society of AIME, 215 (1959) 367–393.
3. Kissling, R. Non–Metallic Inclusions in Steels, The Institute of Metals, London, (1978).
4. Rungta, R., Skidmore,A. J. and Buchheit, R. D. Inclusions: Advantages, Disadvantages, and The Technological Trends, Ed. by R. Rungta, World Materials Congress, Chicago, Illinois, USA, Sept. 1988, ASM International, pp. 1–19.
5. Gladman, T., Holmes, B. and McIvor, I. D. The Effect of Second Phase Particles on the Mechanical Properties of Steel, Iron and Steel Institute Special Report 145, London, (1971), pp. 68-78.
6. SS 111116, Steel–Method for Estimation of the Content of Non–metallic Inclusions–Microscopic Methods–Jernkontoret's Inclusion Chart II for the Assesment of

Non–metallic Inclusion, Swedish Institute for Standards, Stockholm, Sweden (1987).
7. ASTM E45–13, Standard Test Methods for Determining the Inclusion Content of Steel, ASTM, Philadelphia, PA, USA, (2013).
8. Gladman, T. Quantitative Metallography: Recent Experience with Automatic Image analysis, Clean steels 3, Balatonfured, Hungary, (1986) 50.