Developing an Intelligent Quantitative Slab Centerline Segregation Estimator in Steels

Steel slab centerline chemical segregation is an important quality control parameter for critical applications such as oil and gas pipelines, pressure vessels and heavy structural components. Prevalent qualitative estimation tools don't provide ample insights into internal homogeneity of finished rolled products and hence a more quantitative estimation of centerline segregation has been attempted using image analysis software developed in-house. Application and usage of this simple estimator tool for geometrical segregation quantification will be discussed in this article.

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Introduction

Steel slab centerline chemical segregation is a natural process during solidification of steels due to the low melting point of the last alloy-rich solidifying melt. The segregation is prominent for higher-carbon and alloy-rich melts. The segregation affects mechanical properties, soundness, as well as weldability properties of steel. For advanced critical applications such as pipelines for oil and natural gas transmission, storage and pressure vessels, and pressurized tank cars, it is critical that the steel poses sufficient toughness at low temperatures and hence centerline segregation should be at its minimum.[1,2] Centerline segregation is integral to whole-body toughness of components.

In order to eliminate or to minimize centerline segregation in steel slabs, metallurgists have innovated low-carbon, low-alloy steel chemistries and processing that meets stringent mechanical properties. On the other hand, steel manufacturers have resorted to technological installations such as dynamic soft reduction, which contain or minimize segregation to a large extent.[3]

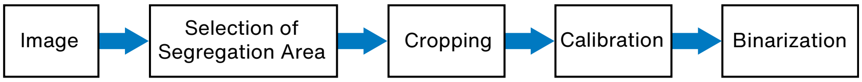
There are metallographic methods within ASTM E381[4] to reveal chemical segregation in cast steel sections and segregation is examined by macroetching a full-width, full-thickness slab section cropped transverse to the casting direction. The centerline chemical segregation is then compared with a classification rating system indicated by Mannesmann[5] and is universally accepted as a benchmark classification system for acceptance by end users. The Mannesmann classification system for segregation is based on a qualitative comparison of segregation intensity and distribution along the centerline of cast slab cross-section with that of the standard charts and the classification based on four distinct segregation intensities, as shown in Fig. 1.

The comparison and thereby classification is entirely based on visual comparison and is not subjected to geometric calibration or quantification; therefore, it is utterly subjective. Today, all pipe manufacturers require a centerline segregation rating of 2 or better as per the above qualification rating for acceptable quality criteria of steel for downstream processing. Ironically, most steelmakers falter in assigning a distinct rating when it comes to a segregation pattern resembling an upper side of 2 or lower 3. The indecision is further aggravated by poor light, low-resolution macrographs, obscure etching and poor eyesight.

Several earlier researchers have attempted[6,7] to assign a quantitative estimation of centerline segregation so that a quantitative rating system

Figure 1

Software workspace.



could be evolved based on density of segregation per unit length/area/volume of metal. Spectra Energy Inc. has evolved a rating guideline[8,9] based on quantitative measurement of segregation spots along the centerline of slabs and assigning a rating based on a logical matrix consisting of size and number of segregation spots. This guideline provides a better quantitative approach to quality benchmarking, but it lacks full support from industry due to applicability and measurement complexity of the segregation spots.

In an earlier work by the current authors,[7] an automated quantitative measurement of segregation spots, geometrical coordinates within the centerline and a comparative evaluation matrix were presented[7] and published.[10] The quantitative estimation of the segregation spots along the centerline of steel slabs provided an approach path to the evolution of a benchmarking for density of segregation that can be easily measured using the software through a pixel-unit length calibration method.

In the current work, the same principles of segregation quantification are adhered to. But the procedural steps have been significantly simplified for ease of use and reporting.

This article describes the easy steps for a quantitative estimation or measurement of centerline segregation spots and the analysis can be used or adopted in scribing an industry-acceptable classification system in conjunction with other established classification systems.

Approach to Quantitative Assessment

Slab Macroetching: For the study of steel slab centerline segregation, usually a full-width slab sample is cropped at the exit of the caster, and the cross-sectional surface is etched using an aqueous 1N hydrochloric acid solution. The etching can be manual or automated through use of electro-etching units, and the key objective is to get distinctly recognizable cast structure and segregation spots. A high-resolution image is then acquired for post-analysis. For ease of operations, the full-width slab is usually cut in to smaller sections, macroetched and images acquired.

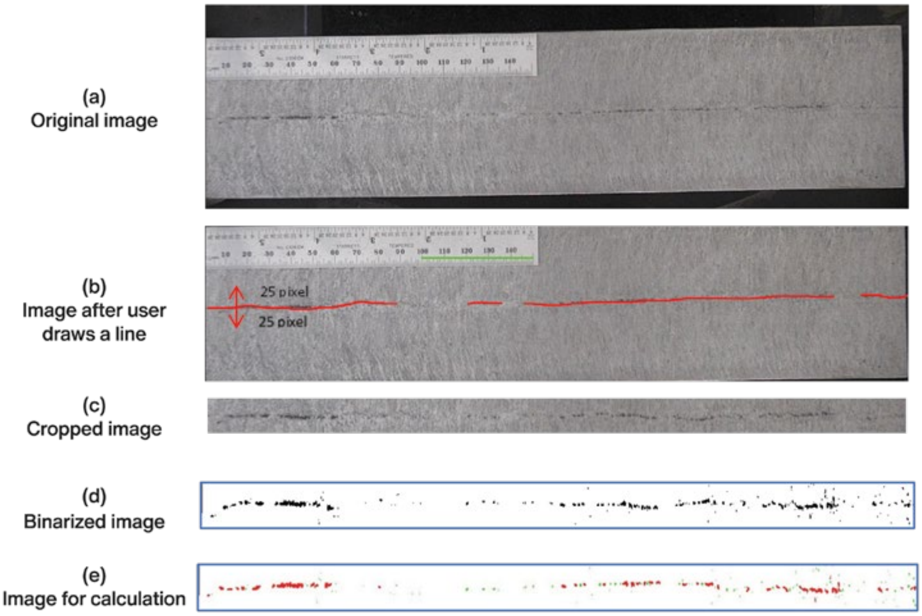
Image Processing Workflow: The software developed has a typical workspace, as shown in Fig. 1. Apart from the command tabs, there are two sliders on the right-hand side that the user can move up and down for segregation spots binarization and placement of the reference points of analysis (say 100 mm length) within the centerline.

The image processing steps are outlined below and are demonstrated in Fig. 2.

First, the macrograph with magnification marker is pasted in the dashboard (Fig. 2a). The image clearly shows the centerline segregation spots. For selection of segregation area of interest, a freeform line is scribed along the segregation length that need not be precisely over the segregation but free traverse over the centerline (Fig. 2b). The user keeps the left button of the mouse pressed and moves the mouse to draw the freeform line to cover the centerline at their best. The line need not be continuous and scribed only over visible segregation spots as shown. For each dot (pixel) on the line, a line covering

Figure 2

Image processing workflow for selection of segregation spots in steel slabs.


(a) Original image

(b) Image after user draws a line

(c) Cropped image

(d) Binarized image

(e) Image for calculation

Figure 3

Tabular matrix.

Dot number from left	Height, mm	Width, mm	Area, mm^2	Location from left of slab	Area of spots within 100 mm length	Total area of spots within the whole slab width

25 pixels above and below the dot is considered to cover all segregation spots along the line. This is done considering the segregation spots often are not linear. This software program automatically selects the area and crops it, and the cropped image is as shown in Fig. 2c. Cropping helps to concentrate only on areas of interest, and distracting irrelevant areas are kept out of the analysis.

For calibration, the user right-clicks on two locations on the ruler to represent 50 mm (shown in green line, Fig. 2b) and the software will calculate pixel-to-mm ratio. This step is necessary, as the software only has the concept of pixel before the user teaches it how many millimeters are represented by one pixel. Drawing a line representing 50 mm reduces the experimental errors (within ± 1 mm).

Binarization: A slider is provided in the dashboard with a pixel range of 0–255 for use to develop the segregation spots to closest matching with the original image as shown in Fig. 4. Moving the slider up and down the line causes the segregation areas to appear light to dark in the frame, and the user chooses the optimum reproduction to his/her satisfaction, as shown in Fig. 2d. Figs. 4b and 4c show how an overestimation and underestimation of the segregation spots can be developed through movement of the slider. For ease of generating the best optimum reproduction (Fig. 4d), the original cropped image is also kept in the frame. Once the optimum reproduction is achieved (Fig. 4d), the program is ready for computation.

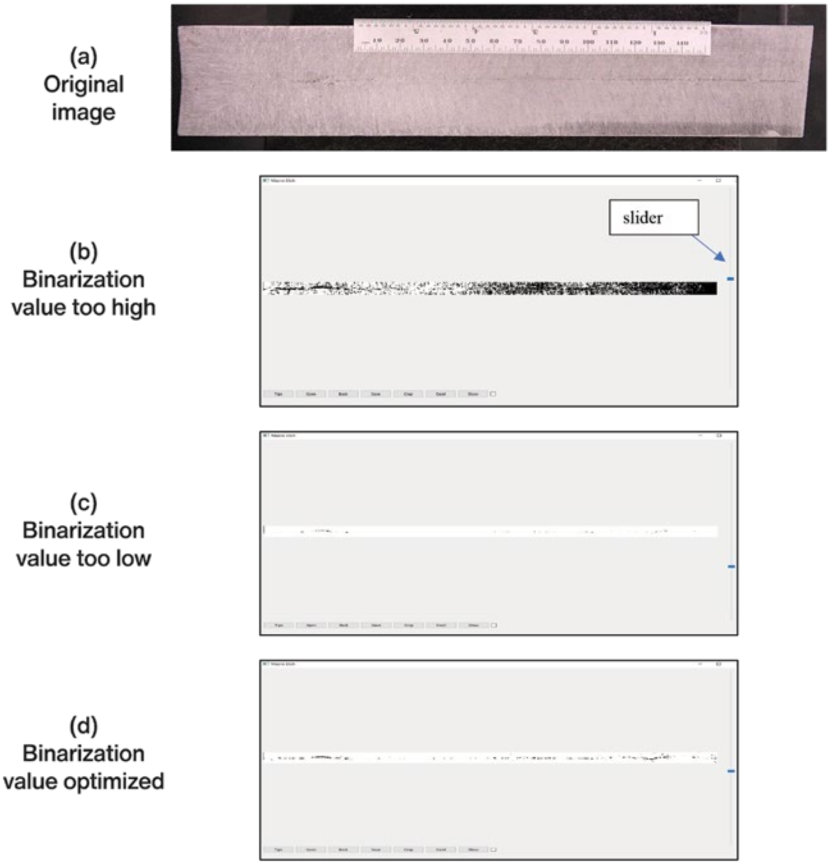
Segregation Quantitative Measurements

The software uses Breadth-first-search algorithm to calculate the dimensions (length, width, size) of each isolated dot. Numerous possibilities can be generated using the program and a typical calculation matrix can be as follows and shown in the tabular matrix in Fig. 3:

- The segregation spot size, location or area can be generated in plain sequential order over the entire centerline length.
- A pixel ratio can be generated as to the segregation intensity over a specific length of the centerline, say 100 mm, as indicated in the Spectra procedure.
- A pixel intensity ratio can be generated as to the sum of area of all eligible segregation spots over the entire width of slab centerline divided by the segregation area.

Figure 4

Binarization using a slider in the dashboard to match as close as original image.


(a) Original image

(b) Binarization value too high

(c) Binarization value too low

(d) Binarization value optimized

The reference length, e.g., 100 mm, can be chosen at regions of worse segregation spots. In the software, all segregation spots with length or width of more than 1 mm are considered and labeled as red and the rest are labeled green (Fig. 2e, Fig. 5). If spots less than 1 mm are spaced within 1 mm, then those spots will be considered one continuous segregation and are taken into the calculation. This is shown in Fig. 5. The slider on the right-hand side of the frame can be moved to select the location of reference "100 mm" in the centerline.

Discussion

The software enables binarization of macroimages of the slab and quantification of each segregation spot. Once optimum binarization is done, the segregation spots are quantified, which allows users to represent the segregation in any mathematical expressions such as pixel ratio with respect to unit length or area of segregation and compare with established classification system. This can be easily applied to the Spectra Rating system, which is based on segregation dot size and numbers in any specific length of the centerline as detailed in Fig. 6.[9]

Additionally, the macroimages of the Mannesmann classification system can also be analyzed using the software and pixel ratio can be estimated for each classification rating. This pixel ratio can be compared with the pixel intensity ratio of the actual slab in question and a classification equivalence can be estimated. This method of quantitative classification has been discussed in detail in earlier publication.[10] The binarization and optimization of segregation in each class of the Mannesmann system is worked out as shown in Fig. 7. Thus, a quantification in terms of segregation ratio per unit length or area can be easily computed.

Figure 5

Dashboard of software for working with macroimages for quantitative analysis.

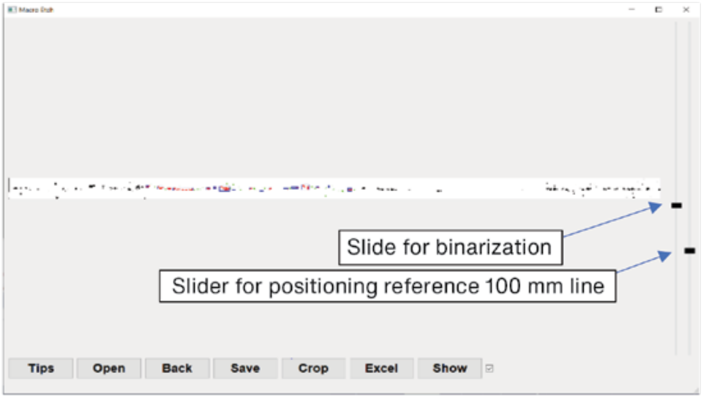
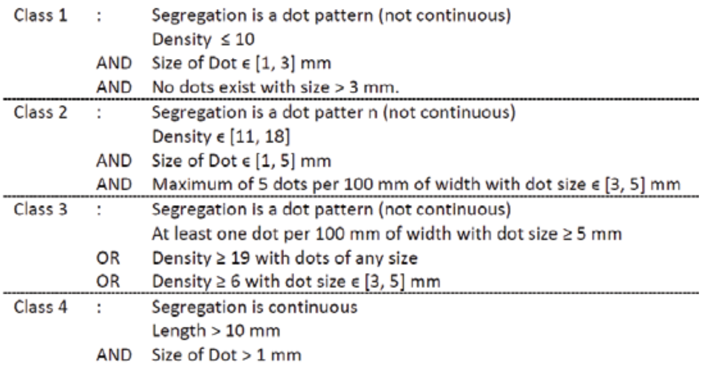


Figure 6

Spectra Rating system.



Class 1	:	Segregation is a dot pattern (not continuous)
		Density ≤ 10
	AND	Size of Dot ϵ [1, 3] mm
	AND	No dots exist with size > 3 mm.
Class 2	:	Segregation is a dot patter n (not continuous)
		Density ϵ [11, 18]
	AND	Size of Dot ϵ [1, 5] mm
	AND	Maximum of 5 dots per 100 mm of width with dot size ϵ [3, 5] mm
Class 3	:	Segregation is a dot pattern (not continuous)
		At least one dot per 100 mm of width with dot size ≥ 5 mm
	OR	Density ≥ 19 with dots of any size
	OR	Density ≥ 6 with dot size ϵ [3, 5] mm
Class 4	:	Segregation is continuous
		Length > 10 mm
	AND	Size of Dot > 1 mm

Summary and Future Work

A graphical user interface (GUI) has been developed as an integrated solution to let the user crop, binarize and filter the slab macroimages and generate a report on the quantitative estimates of segregation spots. The GUI is packaged as an executable file. The software (including key functions) was developed in Python for desktop usage. For web-based application, the author will use C# to develop another GUI version.

The ease of image analysis for quantification will be helpful in developing a rating system for steel slab segregation.

The authors are working to develop an automated system of optimization of the centerline segregation spots so that users don't have to rely on their skills using the slider, and thus the option to choose automated optimum binarization will be handy in generating or replicating the perfect binarization of segregation. The automation will be based on thousands of analyses of macrographs. This process will eliminate any user inflicted error in the optimization process.

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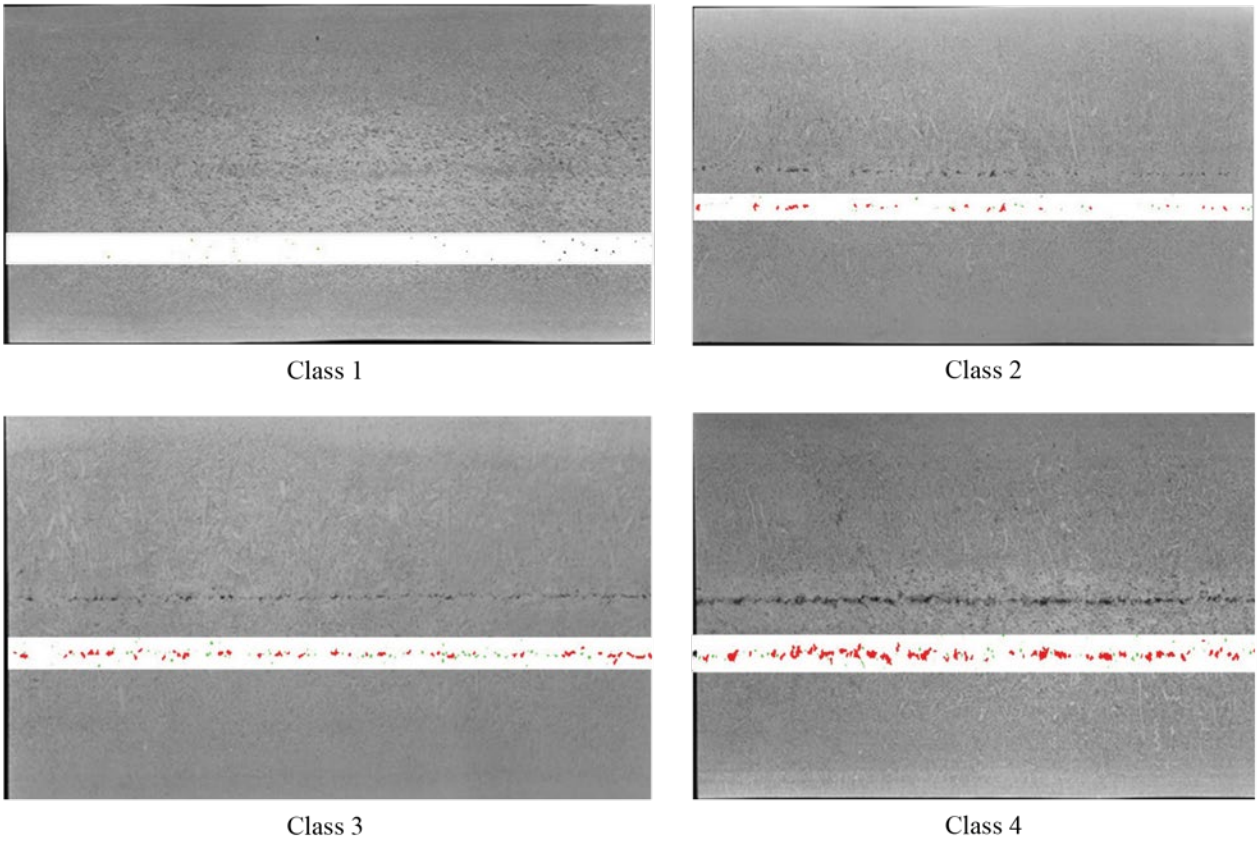
Figure 7

Mannesmann segregation images for classification and mapping of segregation using the current software for quantification of the segregation.



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