Automated Image Analysis of Microstructure Changes in Metal Alloys

Mohammed E. Hoque, Ralph M. Ford, and John T. Roth Penn State Erie, The Behrend College School of Engineering and Engineering Technology Erie, PA 16563-1701

ABSTRACT

The ability to identify and quantify changes in the microstructure of metal alloys is valuable in metal cutting and shaping applications. For example, certain metals, after being cryogenically and electrically treated, have shown large increases in their tool life when used in manufacturing cutting and shaping processes. However, the mechanisms of microstructure changes in alloys under various treatments, which cause them to behave differently, are not yet fully understood. The changes are currently evaluated in a semi-quantitative manner by visual inspection of images of the microstructure. This research applies pattern recognition technology to quantitatively measure the changes in microstructure and to validate the initial assertion of increased tool life under certain treatments. Heterogeneous images of aluminum and tungsten carbide of various categories were analyzed using a process including background correction, adaptive thresholding, edge detection and other algorithms for automated analysis of microstructures. The algorithms are robust across a variety of operating conditions. This research not only facilitates better understanding of the effects of electric and cryogenic treatment of these materials, but also their impact on tooling and metal-cutting processes.

Keywords: Image analysis, microstructure, tooling, and alloys.

1. INTRODUCTION

Manufacturing industries are now under constant pressure to produce high quality parts at minimal costs due to the expansion of international markets. This is a motivating force for manufacturing industries to employ new techniques to increase production while maintaining quality. With the advancement of tooling technology, tungsten carbide has progressively replaced the high-speed tool steels due to its improved resistance, stiffness, and strength. Reducing tool wear is of major significance in tooling industries since it is proportionally related to the production of unacceptable or out-of-specification parts. Therefore extending the cutting tool life not only enhances the production rate, but also reduces tooling expenses. Similarly, if metals being shaped and cut, such as aluminum alloys, can be made easier to cut for a short period of time without any negative long term effect, then less energy is required and there is also an increased tool life.

Empirical studies have demonstrated that the life of cemented tungsten carbide cutting tools can be increased by cryogenic treatment^{1,5,6}. Furthermore, the energy required in aluminum deformation processes can be reduced by electrical treatment of the piece while under it is being worked. When these alloys undergo the cryogenic and electronic treatments changes occur in the microstructures of the material. However, the mechanisms of the microstructure changes under the various treatments, which cause them to behave differently, are not yet fully understood. These changes are evaluated by examining images of the microstructure, yet they are currently evaluated in a qualitative manner.

The objective of this research is develop imaging and recognition technology to quantitatively measure the changes in microstructure in the different etching phases of cryogenically treated tungsten carbide alloys and in electrically treated aluminum alloys. Ultimately, these results will be used to compare different treatment methods and their impact on tool life and metal ductility. The paper is organized as follows. Section II provides background on both the image acquisition process and microstructure images. Section III describes the recognition algorithms employed and results obtained for aluminum alloys, while Section IV addresses the processing and results for tungsten carbide images. Section V provides conclusions and future work.

II. BACKGROUND

Aluminum alloys examined in this application are the metals that are being deformed and cut through the manufacturing process. In such an application high electrical current is passed through the alloy, which is electrically isolated from the cutting machinery. Again, empirical studies have shown promise in reducing the amount of energy required to mill the piece. The objective of this work is to address the machine vision aspects of the microstructure images. To compare, the microstructure of materials that are not electrically treated are compared to those that are electrically treated. This is done by examining the material using microscopy – in these experiments both a metallograph and scanning electron microscope (SEM) were used. The method that best identifies the phenomena under consideration is selected. Prior to examining them the aluminum undergoes a chemical etching phase to expose alloy precipitates. An example of an aluminum alloy image obtained from a metallograph is shown in Figure 1. The alloy precipitates present in the image are represented by the blobs which are fairly distinctly distinguished into two shades of gray – the white blobs which are the lighter ones and the darker or grey blobs. The objective is to identify the two types of blobs and statistically characterize them for comparison purposes. The white blobs represent Fe₃SiAl₁₂, Fe₂Si₂Al₉, Mn₃SiAl₁₂, or Cr₃SiAl₁₂. The dark blobs represent Mg₂Si precipitates all the blobs depending on their intensity differences along with measuring their area and sizes after and before electrical treatments is a yardstick to confirm the initial assertion on tool life increase.



Figure 1. Aluminum alloy sample captured using the metallograph with 1175X magnification. The visible blobs are to be isolated into two categories – white and grey.

The processing of the tungsten carbide alloys is a bit more complicated. In this case, the material undergoes successive chemical etching steps to expose three different phases of the material – eta, gamma, and alpha. In many cases, the formation of eta phase causes embrittlement of the tool. The alpha phase contributes to higher tool hardness whereas gamma phase is related to the material properties of the tool. Figure 2 contains images of tungsten carbide of different phases in 800X magnification. Being able to measure the discrepancy of the region of interests before and after cryogenic treatments as shown in the images would be a strong determinate to support the assertion of increased tool life for tungsten carbide under cryogenic treatment. The eta phase contains dark flecks that directly reflect the tool life, the gamma phase contains fleck-like particles, and the alpha phase includes grey angular shaped regions. Both the size and number of particles in the gamma and alpha phase reflects the material hardness and tool life.



Figure 2. Images of tungsten carbide alloy before and after cryogenic treatment. Three phases produced by etching are shown.

III. PROCESSING OF ALUMNIMUM ALLOYS

The processing of the aluminum images is fairly straightforward since there is good contrast between the blobs and background. The processing approach was to apply illumination correction, followed by adaptive thresholding, and then by the detection of the contours of each blob. The individual blobs were then classified as either white or grey and the statistics for each computed. The processing algorithm is now examined in more detail.

The aluminum images have inconsistent distribution of illumination due to light concentration from the metallograph image acquisition system. This is particularly apparent in the corners of the image. Since the main objective was to isolate the dark and gray blobs based on their intensity levels, a background correction algorithm was performed to compensate for the inconsistent pixel intensity of the background. This minimized the possibility of dark and gray blobs being misidentified. A minimum rank order filter then applied to reduce noise and further produce a uniform distribution of illumination. It was found that a filter with a window size of ten produced a good compromise between performance and processing time.

Adaptive thresholding was found to be effective and produced results that are far better than can be achieved with a global threshold. Adaptive thresholding was more effective at maintaining the original shapes of the particles. The blobs were then labeled and their contours encoded using 8-connected Freeman coding. To simplify the representation a polygonal approximation was used to minimize the number of points representing the contour. Local maxima points of curvature are located on the contour. All of the pixels bounded by each contour are then labeled. The process of blob identification is shown in Figure 3.



(a) Original aluminum image.

(b) Adaptively thresholded image.



(c) Classified partical blobs.

Figure 3. Processing of aluminum images.

The blobs are then processed to determine their size and average intensity values and they are separated into gray and white blobs based upon a threshold of the average blob intensity value. The results of the blob analysis for the aluminum images with different treatments are shown in Table 1. Some striking effects on aluminum due to electrical treatment are evident in Table 1. All the treatments decrease the amount of dark blobs by 96%-99%, the number of regions where dark blobs appears by 87%-91% and average size by 51%-90%. The dark blobs are directly proportional to the firmness of the aluminum and our objective is to temporarily reduce it without having any long term effect. Therefore, this consistent reduction of dark blobs is well supported by the data. This can be directly correlated to the initial assertion of lessening in strength and specific energy of aluminum by electrical treatments. Thus the imaging approach yields clear quantitative data to support the assertion.

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	0 Amps	Annealed	1350 Amps	Annealed and 1350 Amps	Electrically Preheated	Applied Heat
# of blobs						
Total blobs	181	255	163	249	188	126
# of dark blobs	23	2	3	2	2	2
Total blob area (pixels)						
Total area occupied	3258	3825	4401	6225	5452	5796
Total dark blobs area	1357	58	45	13	56	46
Average blob size (Pixels)						
Average blob size	18	15	27	25	29	46
Average dark blob size	59	29	15	6	28	23

Table 1. Results generated by the image analysis program of different images of Aluminum alloy.

IV. PROCESSING OF TUNGSTEN CARBIDE ALLOYS

As previously noted, cryogenic treatments were found to improve the tool life of the various tungsten carbide tool inserts. In order to quantitatively measure the difference between the successive chemical etching steps of three phases (eta, gamma, and alpha) were separately investigated.

The eta phase, when examined with the metallograph, has asymmetrical shapes that emerge as darker flecks as shown in Figure 4. A reduction of the size and number of flecks after the cryogenic treatment is a strong determinate of increased tool life. Therefore, the comparison between the area of the dark flecks before and after the cryogenic treatment was performed. A simple task of adaptive thresholding was adequate to accomplish the comparison and the results are shown in Figure 4.







(c) Cryogenically treated eta phase.

(d) Detected flecks.



The image analysis identified that 21.43% of the flecks were dark in cryogenically treated images versus 31.73% for the untreated images. This is a clear indicator that the tungsten carbide is stronger after cryogenic treatment since the eta phase formation is directly related to the embrittlement of the tool.

The distribution of the gamma phase plays an important role in determining how well the cutting tool maintains its properties. A fine dispersion of inhibitors in the material more uniformly restricts grain growth and it is expected that improving dispersion increases tool life. Additives are inserted in small amounts to effect a desired change in properties, which are normally found in large clusters, or veins, or evenly scattered as shown in Figure 2. The task with the gamma phase is to locate the vein like areas and to compare the changes that take place to those regions after being cryogenically treated. A contour detection algorithm was applied to detect the darker vein-like regions. The gamma phase images were subjected to adaptive thresholding before contour detection. The dark holes or regions, that were not part of the continuous vein like darker regions, were discarded by specifying a minimum acceptable area for each region bounded by the detected contours. The veins were then labeled as shown in Figure 5 and the size of the veins determined. The results show over a 50% average reduction in size of the veins.



(c) Cryogenically treated gamma phase.



Figure 5. Analysis of the gamma phase images.

The final phase examined is the alpha phase, and these images were obtained using a scanning electron microscope to better identify the regions. The alpha phase consists of roughly 90% of the tool's composition representing the core of the tool. The images captured of the etched alpha phase contain grey angular shaped regions. Smaller size alpha grains correspond to higher tool hardness. Based on visual observations, the average grain size of the cryogenically treated alpha phase appears smaller than the untreated ones. However, being able to compute the average increase of angular shape regions, after being cryogenically treated yields better understanding of how much of tool life increase is achieved.

Contour detection is not very effective for identifying the shapes in these images due to the inextricable overlap of some blobs with each other. Some images require human observation to identify the discontinuation of borders, particularly for overlapped regions, making it difficult to fully automate the system. The approach employed was to adjust the contrast of the images and apply Canny edge detection to locate the points representing the borders of each irregular shaped region. The use of hysteresis thresholding to eliminate isolated noisy edges in the Canny edge algorithm was particularly suitable for this set of images. Due to the different level of contrast in most of the areas of each image, other methods examined captured false edges which the Canny edge algorithm tends to reject. The edges identified are superimposed on the original image to allow any necessary further processing for closely conjoined regions. Among all the image data examined, approximately 10% of identified regions were joined required separation by human intervention.

Two temporary methods were proposed to rectify this problem. The first is to specify the maximum area of the detected regions thus eliminating areas where region overlap exists. In this method the maximum area for any detected region is specified by the user and therefore, any regions which have bigger area than the specified are disregarded. Even though possible information loss can occur in this method, it maintains the accuracy of the system without any manual input. The second method is to manually draw lines into inseparable regions to prevent any information loss. The imaging results of this technique are shown in Figure 6, and the corresponding quantitative results show a significant decrease in grain size for the cryogenically treated material.



Figure 6. Analysis of the alpha phase images.

The overall results for all three phases, shown in Table 2, are affirmative in favor of increased tool life after cryogenic treatment. As explained before, alpha phase comprises of 90% of tungsten carbide, and having smaller size grains means higher tool hardness, and this improvement of tool life. Apart from the two samples in Table 2, other alpha images constituted an average grain size decrease of 30-60%. For the gamma phase, the objective was to identify and compute the area of the vein-like regions and perform a comparison between untreated and cryogenically treated images. For all the samples examined there was more than a 50% decrease in vein like regions after cryogenic treatment. This improved dispersion of the vein-like regions corresponds to an increased tool life. Similarly, the eta phase images also showed consistency in having reduced amount of dark flecks, after being cryogenically treated. The percentage reduction of dark flecks fluctuated between 20-40% which is proportionally related to the embrittlement of tungsten carbide.

Alpha phase			Average size of grains (pixels)	Amount decreased (%)	
Images	Sample 1	untreated	2078.35		
		Cryo treated	1320.92	35.44	
		Untreated	3939.43		
	Sample 2	Cryo treated	1499.98	61.92	
Gamma phase Images			Area of interest (i.e. vein like regions) in respect to the whole image (%)	Amount decreased (%)	
	Sample 1	Untreated	17.69	56.64	
		Cryo treated	7.67		
	Sample 2	Untreated	18.83	53.63	
		Cryo treated	10.09	55.05	
Eta phase Images			Amount of dark flecks in the image (%)	Amount decreased (%)	
	Untreated		31.73%	32.4	
	Cryo treated		21.43%		

Table 2. Results for tungsten-carbide images.

V. CONCLUSIONS AND FURTHER WORK

This paper addressed the use of imaging and pattern recognition techniques for the analysis of microstructure images of aluminum and tungsten carbide alloys. The objective is to support research in machining processes used in manufacturing. Studies have demonstrated that the life of cemented tungsten carbide cutting tools is increased by cryogenic treatment, while the energy required in aluminum deformation processes is reduced by electrical treatment of the sample. The application of imaging techniques to quantitatively analyze the microstructures facilitates the validation of assertions using various treatments quantitatively and efficiently, and is not dependent on subjective human observation.

The imaging tools used for the analysis of aluminum alloys were adaptive thresholding to identify precipitate particles followed by analysis of the resulting particle blobs. The size and shapes of the particle were determined and the particles segmented into different types – either Mg_2Si or a variety of other possible types. Currently there is no automated thresholding which is used to isolate the grey and white blobs in the aluminum images, and it requires user input. Future work will examine automated thresholding to eliminate the need for manual input. In the case of the tungsent carbide images, there are three phases that are examined – eta, gamma, and alpha. Each has slightly different characteristics that are examined. The eta and gamma phases were handled effectively with thresholding and blob analysis. The alpha phase has angular particles that need to be individually identified. This was accomplished by Canny edge detection and subsequent analysis of the edges. About ten percent of the alpha phase images required manual input from the user to be

processed further due to connectedness of particles. Future work will focus on identifying these cases and automatically separating them. Overall, the techniques have proven very effective in quantitatively characterizing the changes that occur under the different treatments, and in supporting the findings of increased tool life.

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