AI-based metallographic determination

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Summary

Metallographic examinations are essential for confirming the performance of metal parts. However, examination results varied depending of the proficiency of the examiner because the complexity of the examination details requires sufficient experience. Therefore, a tool was made for classifying metallographic structures using artificial intelligence (AI) for the purpose of assisting the determination of iron-based metallographic structures. This article describes the AI-based tool that has been confirmed to be effective to a certain extent in classifying metallographic structures.

1. Introduction

Metallographic examinations are essential for confirming whether the metal parts of products like continuously variable transmissions (CVTs), automatic transmissions (ATs) and production equipment satisfy the performance intended by their design. This is especially true for ferrous metals. Metallographic examinations involve specimen preparation, observation and structure determination. However, metallographic structures change in complex ways depending on the type of material, processing conditions and heat treatment conditions, among other factors. Since sufficient experience is required for the examiners, variation of determination result occur depending on the proficiency of the examiners.

This article reports the activity of tool preparation for classifying eight types of metallographic structures using AI for the purpose of assisting the determination of iron-based metallographic structures.

2. Present situation

The procedure and details of a metallographic examination are shown in Fig. 1. The specimen preparation processes for a metallographic examination consist of sectioning, embedding, polishing and etching. Finally, a prepared specimen undergoes microscopic observation for determining the microstructure. Technical skill is required for polishing and etching and metallographic determination requires knowledge.

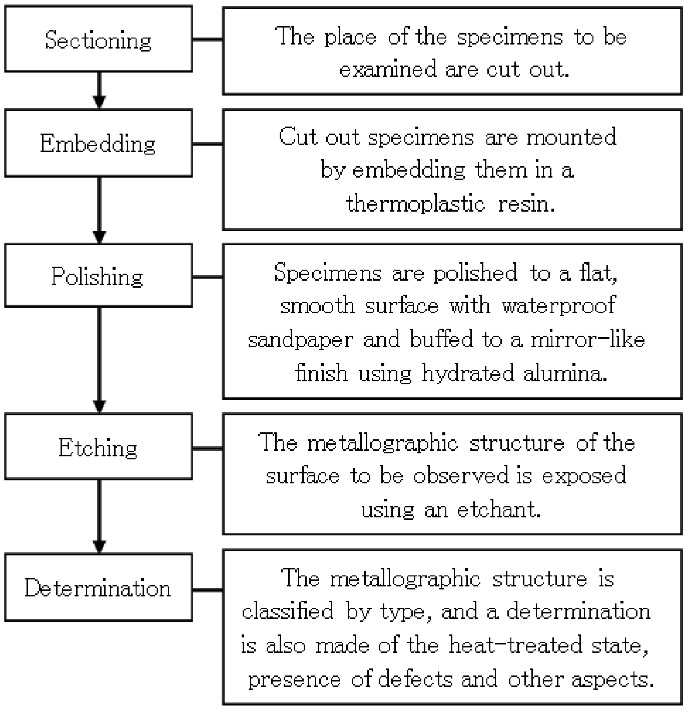

Fig. 1 Metallographic examination procedure and descriptions

The knowledge needed especially for determination requires visual experience. Variation of determination results stemming from insufficient examination experience is an issue. It is also an issue in harmonizing the determination level of metallographic examinations at each testing site including those overseas.

The following two points concern factors causing variation.

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1) Factors originating in the images themselves such as scratches occurring during polishing and etchant bleeding caused by insufficient washing.
2) Factors originating in the examiner's experience with the classification of metallographic structures at the time a determination is made.

2.1 Influence of polishing and etching

First, regarding point 1), polishing and etching are critical procedures for the subsequent determination. Proper processing of specimens leads to an accurate determination.

Insufficient polishing gives rise to scratches and unevenness. Excessive or deficient etching as well as insufficient washing can cause etchant bleeding.

These phenomena affect the subsequent determination.

2.2 Classification of metallographic structures

With regard to point 2), the state of metallographic structures changes depending on the type of material and the processing and heat treatment conditions. Consequently, a specimen may look different from general samples of metallographic structures, rendering classification difficult and causing an incorrect determination.

As a typical example in this regard, Fig. 2 shows differences in the general appearance of sorbite.

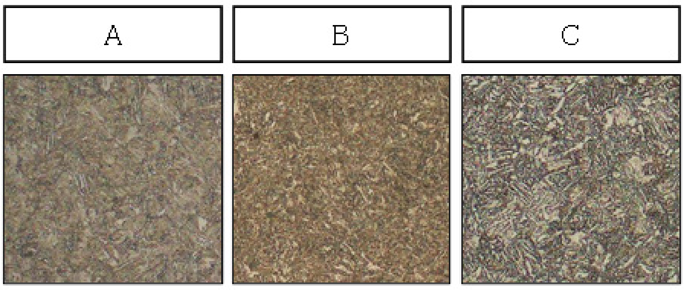


Fig. 2 Metallographic structure of sorbite

3. Preparation of a tool for classifying metallographic structures

In consideration of the factors mentioned in chapter 2 above, it is necessary to classify images of metallographic structures correctly in order to make proper determinations. There are various measures for preventing incorrect determinations, such as making a memo of points requiring attention or preparing a large volume of sample images. However, all of them depend to a large extent on the experience of the examiner.

Therefore, a heat-treated structure was taken as an example in this study in an effort to prepare a tool for automatically classifying if the metallographic structures captured in images are martensite or sorbite.

An examination of various automation methods, including different image processing and logic creation procedures, revealed that making such a tool would involve a high level of difficulty.

Further investigation indicated that automation would be possible by using AI. It was decided to adopt AI because it would involve fewer procedures than the methods mentioned above and provide a higher degree of versatility.

It was envisioned that users of the tool would be examiners having around one or two years of experience with metallographic examinations.

4. Selection of images for training the AI-based tool

Since one examiner would perform all the processes involved in a metallographic examination of a specimen. In order to enable metallographic structures to be classified correctly, low-quality images were also included in training the AI-based tool in consideration of the uncertain elements present at the time of specimen preparation.

Figure 3 shows typical examples of uncertain elements present when specimens are prepared. If the AI-based tool were taught only high-quality images of specimens prepared by proficient examiners, it would not be able to correctly classify actual low-quality images.

Taking scratches as an example, a high-quality image has few scratches while a low-quality image has many scratches. The lower the quality of the image, the more the accuracy rate of the tool would decline.

It was necessary to give the tool versatility by training it both high- and low-quality images so that it would be able to classify even images of poor quality.

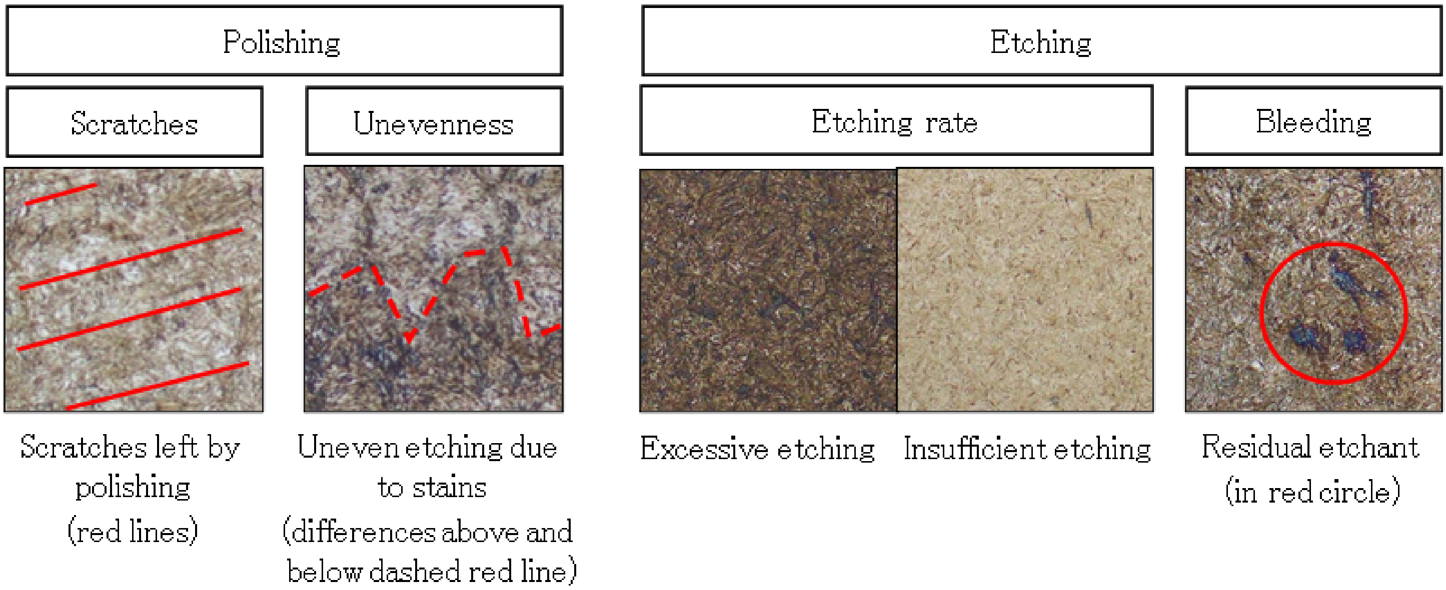


Fig. 3 Typical uncertain elements at the time of specimen preparation

4.1 Scratches

Scratches are often caused by insufficient polishing, among other factors. Images containing scratches were also included with the aim of enabling the tool to classify even images with scratches.

4.2 Unevenness

Unevenness can occur during etching due to insufficient polishing or insufficient washing. The occurrence of unevenness and its degree can vary depending, for example, on the material of the specimen. Therefore, to target materials which unevenness is apt to occur, used images which for containing unevenness for training. The aim was to enable the tool to classify even images in which unevenness is partially shown.

4.3 Etching degree

Etching gradations involve a variety of factors, but the principal factor is variation in the number of seconds a specimen is immersed in the etchant. Images were also included in which etching gradations were intentionally varied by changing the number of seconds for etchant immersion. The aim was to enable the tool to classify even images in which the etching degree differs.

4.4 Bleeding

Bleeding is principally caused by residual etchant that oozes out from a gap in a specimen owing mainly to insufficient washing after etching, among other factors. Images of different degrees of bleeding were also included, limited to materials for which bleeding is apt to occur. The aim was to enable the tool to classify even images showing some bleeding

4.5 Effectiveness of image selection

As explained above, images were selected and taught to the tool for enhancing its versatility. The proportions of the number of images for training were adjusted based on the training results.

As a typical example, Fig. 4 shows the results obtained for training images containing scratches.

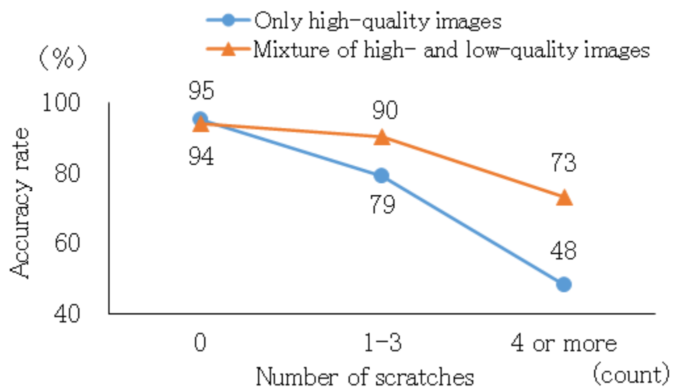


Fig. 4 Accuracy rate as a function of the number of scratches

A comparison was made of the results obtained for training only high-quality images and for training a mixture of both high- and low-quality images. The results revealed that a high correct rate was obtained in the latter case even for images containing scratches.

5. Consideration of effectiveness

Separate from the images used in training, images for tool validation were also prepared in advance and their classification was confirmed by a proficient examiner. Those images were then classified by the AI-based tool. The results showed that the tool achieved an accuracy rate of 90% compared with a rate of 100% for the proficient examiner.

The 90% that were correctly classified also included images in which the appearance of sorbite and other aspects were vastly different. This result confirmed that the purpose of this project was accomplished, which was to assist examiners who make incorrect determinations due to insufficient knowledge. It was concluded that the AI-based tool can reduce variation in classification results.

The 10% inaccuracy was largely due to materials that underwent plastic deformation or contained troostite. Because materials that experience plastic deformation or contain troostite are difficult to classify even for proficient examiners this result could be expected.

6. Conclusion

(1) It was confirmed that using AI can assist in making determinations of metallographic structures.
(2) It was also recognized, in consideration of image quality, that it is important to train the tool images containing confirmed uncertain elements in order to raise its accuracy rate.
(3) Based on the envisioned details, the tool was successfully made. Examinations to be done by human examiners and examinations that can be entrusted to the AI-based tool were confirmed.

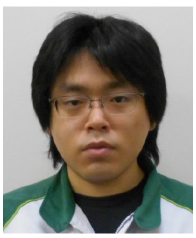
7. Future issues

The tool made in this project only has a function for classifying. It is desired to equip it with an additional function for displaying advice in cases where image quality is low because specimen preparation did not go well. Such advice would prompt in correcting the details of preceding processes, such as insufficient polishing or dark etching.

It is also planned to improve the tool so that it can be deployed at other places where similar metallographic examinations are performed.

To make it realized, activities for increasing the accuracy and the number of metallographic structures that can be classified will be continuously taken.

■ Author ■



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