Comparison of Eye Movement During the Polishing Process of Metallographic Sample Between Expert and Nonexpert

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Abstract. The carburizing process requires metallurgical inspection by means of polished metallurgical mounts. Metallographic preparation for a metallurgical mount is an important process for the quality assurance of the carburizing process. The purpose of this study is to clarify the expert's characteristics of polishing process based on the eye movement analysis. Two inspectors with 20 (hereinafter referred to as "expert") and 0.5 years (hereinafter referred to as "nonexpert") of experience in metallographic preparation were interviewed and their eye movement analyzed. As a result, the expert made pressure adjustments and cleaning the surface and supplying alumina as needed while performing the polish.

Keywords: Polish · Metallographic preparation · Eye movement analysis

1 Introduction

The most common heat treatment process for hardening ferrous alloys is known as carburizing. Usually one or more test specimens for quality assurance accompany the carburizing process. The quality assurance of the carburizing process requires metallographic analysis of case depth, core hardness, intergranular oxidation, network carbide, and retained austenite with an optical microscope at × 100–1000 magnification by means of metallographic mounted samples. An accurate metallographic analysis is very important for heat treater to develop their process or improve their product reliability [1–3].

To achieve an accurate analysis, the true microstructure of the carburized part must be preserved during the metallographic sample preparation. Unfortunately, case-hardened part such as carburized part has several hardness variations in a single part that would normally require difficult grinding/polishing operations, especially with complicated shape part such as gear part. As a result, harmful scratches or the rounding or the specimen has occurred on the polished surface. If the sample has such problem, it leads wasting of time and money because re-grinding and polishing operations are

V.G. Duffy (Ed.): DHM 2015, Part I, LNCS 9184, pp. 399–410, 2015.
DOI: 10.1007/978-3-319-21073-5_40

required. Metallographic preparation consists of sectioning, mounting, grinding and polishing, and etching. Herein, we focus on the grinding and polishing process.

Grinding and polishing of a mounted sample removes sectioning damage and creates a polished surface for evaluation. This process is usually performed manually (handheld) or by automated method with many sizes of an abrasive.

In fact, the surface finishes of metallurgical samples of carburized gears differ between expert and nonexpert preparations even though grinding and polishing are performed by semi-automated machine. In other words, it is difficult for a nonexpert to continuously supply stable conditions (i.e., minimum scratch and limited edge rounding) for a metallographic sample. In particular, a case-hardened gear part such as a carburized gear is difficult to grind and polish because the grinding and polishing rate varies depending on the hardness of the mount, which consists of metal and mount materials although mirror finishes and edge retention are required for near-surface inspections. Many techniques for grinding and polishing are contained in standards or technical documents [4–8]. Metallographic preparation for thermal sprayed sample has been studied [9]. However, no research has focused on the difference between the grinding and polishing of metallographic sample by experts and nonexperts. This research compares and contrasts the eye movements of an expert and non-expert as they each perform grinding for metallographic sample, then clarifies the characteristics of the work of the experts.

2 Measurement Method

The subjects were a researcher with 20 years of experience (the expert) and another one with 2.5 years of experience (the non-expert). A 9310 (AMS6265) gear (pitch diameter: 24.5 mm), cut into a quarter of a gear consisting of four teeth, was used as a sample. The subjects were given samples that had already undergone heat embedding, the final step before grinding and polishing, which were to be performed by the expert and non-expert using a semi-automatic grinding machine (by Refinetec, STO-228 K). The grinding sheet used was P120, P400 SiC grinding sheet. The polishing was done by P1200's SiC grinding sheet and 5 μ, 0.3 μm of alumina. Eye movements were measured with Talk Eye II by Takei Scientific Instruments Co., Ltd. at a sampling rate of 30 Hz. The final roughness measurement was performed with an ultra-precision measurement system (Talysurf PGI by Taylor Hobson). After the grinding work was completed, the subjects were interviewed as needed, and researchers studied what eye movements of the expert corresponded to a surface finish that had minimal inconsistencies.

3 Results

3.1 The Position of Subject's Hand and Line of Vision

Figure 1 shows the position of the subject's hand and line of vision during the SiC grinding.

P120. The expert's line of vision was on the rotation speed adjustment control of the grinding board for 9.1 s, 10.2 s after he began the grinding work. During that time, his hands stayed on the control, and after 19.5 s, his eyes were focused on the pressure control handle until 29.4 s. Until the grinding work was done at 81.7 s, the expert's eyes went back and forth 8 times between the pressure control handle and the rotation speed adjustment control. The expert's hands stayed on the pressure control handle for 19.1 s from 17.3 s, gradually increasing the pressure, and never returning to the pressure control handle.

On the other hand, after staying on the pressure control handle for 1.8 s from 1.1 s, the non-expert's eyes never returned to the pressure control handle until the end of the grinding work, his eyes instead going between the grinding board and elsewhere. The non-expert's hands were on the pressure control handle from 1.0 s for 1.8 s, but they never went back there.

P400. The expert's eyes were on the pressure control handle 1.2 s after he began grinding and went back and forth 11 times between the pressure control handle and the grinding board or the clock until he completed the grinding work. His hands stayed on the pressure control handle for 25.0 s from 6.9 s, applying pressure gradually.

The non-expert, on the other hand, had his hands on the pressure control handle from 2.2 s for 1.8 s, but never to return until after the grinding was complete at 40.8 s. His eyes went back and forth between the grinding board and the clock. His hands were on the pressure control handle from 2.3 s for 1.8 s, but after that, they never returned to the pressure control handle.

P1200. The expert's eyes stayed on the pressure control handle for 1.8 s, 2.2 s after the grinding rotation board began operating. Until the end of the grinding work, his gaze traveled from the pressure control hand to the grinding board or the clock four times. The expert's hands were on the pressure control handle for 19 s from 4.9 s onward, gradually increasing the pressure.

On the other hand, the non-expert's gaze stayed for 2 s on the pressure control handle 1.1 s after the grinding rotation board began operating. From then on, his gaze never went back to the pressure control handle until after the grinding work was complete, but went back and forth between the grinding rotation board and elsewhere. The non-expert's hands were on the pressure control handle for 1.8 s from 2.0 s, and after setting the pressure until the grinding work was done, they never went back to any grinding work.

Figure 2 shows the position of the subject's hand and line of vision during the Alumina polishing.

5 μm. The expert's gaze stayed on the rotation speed adjustment control for 4 s, 0 s after the grinding rotation board began operating. His hands were on the rotation speed adjustment control for 4 s from 0 s, adjusting the rotation speed. From 7.1 s, the expert's gaze went back and forth five times between the pressure control handle and the grinding rotation board for 17.9 s. The expert's hands were on the pressure control handle for 6.8 s from 11 s, gradually applying pressure. From 23.8 s until 90.1 s, his gaze traveled back and forth between the alumina bolt and the rotation board eight times. During this time, his hands were on the alumina bolt and water supply nozzle, reaching for the alumina twice and water once for rinsing purposes.

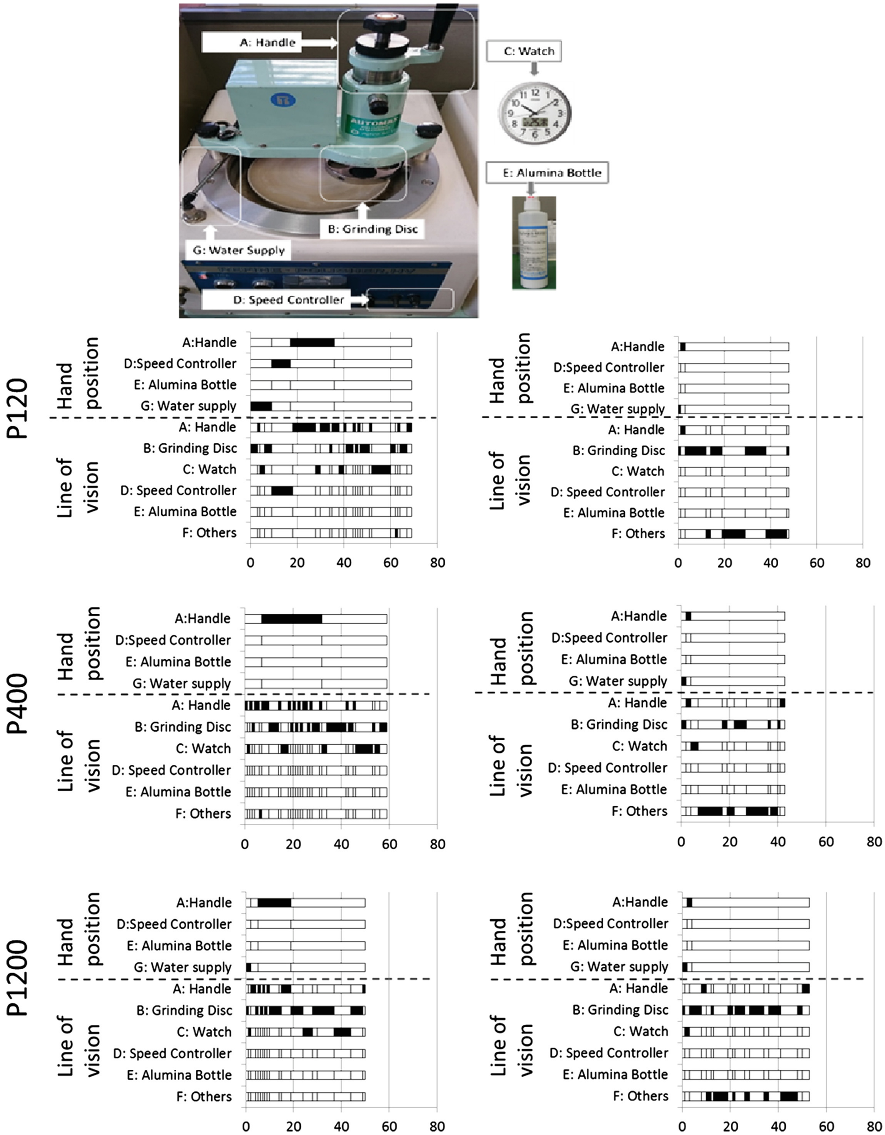

Fig. 1. The position of the subject's hand and line of vision during SiC grinding

The non-expert's eyes stayed on the pressure control handle from 0 s for 1.8 s, but never went back there until the end of the grinding work. His eyes went back and forth four times between the grinding board and the alumina bolt from 3.0 s, reaching for the alumina three times, the water once.

0.3 µm. The expert's eyes stayed on the grinding board from 0 s for 9.9 s, his hands on the water supply nozzle from 0 s to 9.8 s, cleaning the grinding board. His gaze went

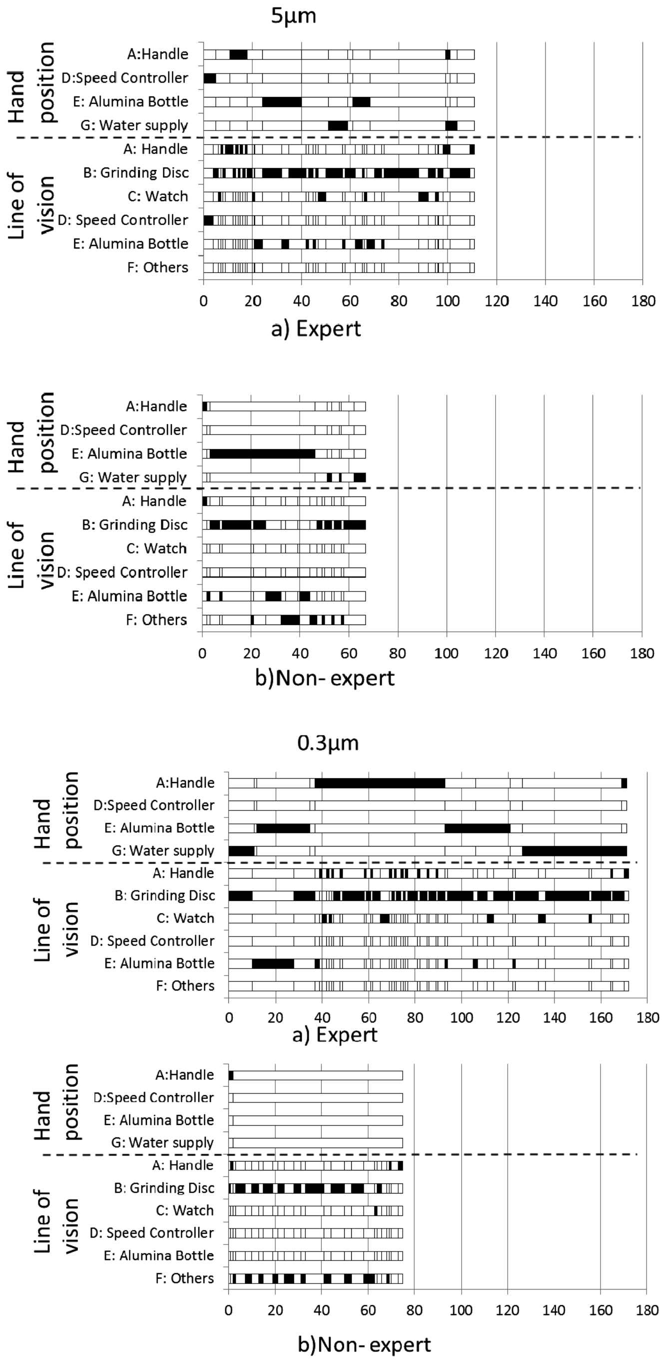

Fig. 2. The position of subjct's hand and line of vision during Alumina polishing

back and forth 13 times from 39.9 to 93 s between the pressure control handle and the grinding or the clock. His hands were on the pressure control handle from 37.2 to 92.8 s, applying gradual pressure. The expert's eyes went back and forth three times between the grinding board and the alumina bolts between 93.9 and 123.3 s. His hands were on the alumina bolts from 93.9 to 121.2 s, incrementally supplying the grinding board with alumina. The expert's eyes went from the grinding board and the clock twice between 123.2 to 170.5 s. His hands stayed on the water supply nozzle from 126.4 to 169.1 s, anticipating the friction from the resin to blacken the grinding board and cleaning with water.

The non-expert's eyes were on the pressure control handle from 1.2 to 2.1 s, but never returned after that until he was done with the grinding work. From 3.8 s onward, his gaze went back and forth between the grinding rotation board and elsewhere, but his hands would never perform any grinding work.

3.2 Eye Movement Speed of the Subjects

Figure 3 shows the eye movement speed of the subjects. The speed of the left eyeball movement while using the SiC P120, P400, and P1200 grinding, as well as 5- and 0.3-micrometer alumina grinding, was slower for the expert than the non-expert.

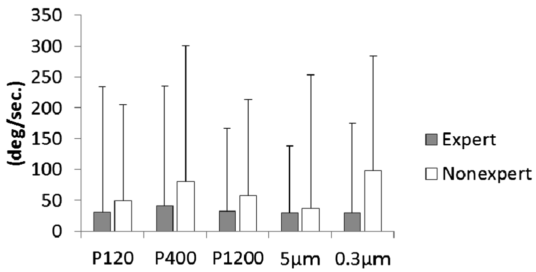

Fig. 3. The eye movement speed of the subjects

3.3 The Length of Time of the Subjects' Gaze

Figure 4 shows the length of time of the subjects' gaze during the grinding work.

The expert's gaze was longer than the non-expert's during grinding work, using SiC's p120, P400, P1200 and 5- and 0.3-micrometer alumina grinding. The expert's length of gazing time, in particular while using P120, was longer than the time he spent looking while using other polishing grains.

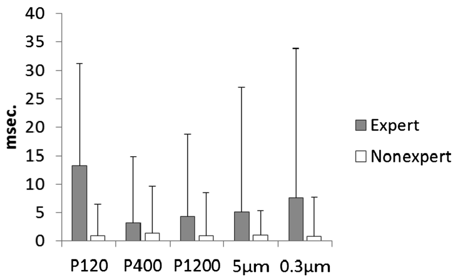

Fig. 4. The length of time of the subjects' gaze

3.4 Characteristic Movements of the Subjects' Eyeballs During Grinding Work

Figure 5 shows characteristic movements of the subjects' eyeballs during grinding work. While adjusting the grinding pressure, the expert fixed his gaze on the grinding handle itself and let it follow the rotation of the handle. Furthermore, while increasing the pressure by rotating the handle, the expert let his gaze go back and forth between the grinding board and the handle. The non-expert, by comparison, moved his gaze to where he was about to set the handle, and unlike the expert, didn't allow his gaze to follow the movement of the handle. Also, the non-expert's gaze while adjusting the pressure didn't go back and forth between the grinding board and the handle.

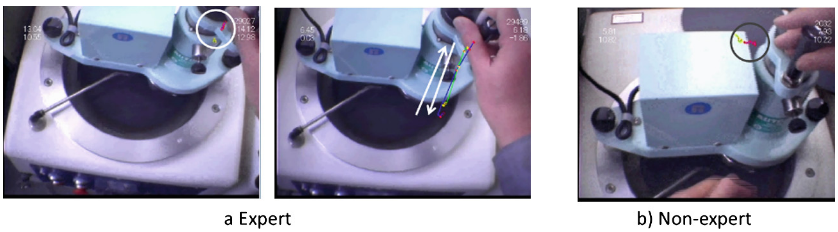

Fig. 5. Characteristic movements of the subjects' eyeballs during adjusting pressure

3.5 The Speed of the Subjects' Left Eyeball Movement

Figure 6 shows the speed of the subjects' left eyeball movement while observing the polished surface. After grinding work with all the SiCs was complete, the expert was slower than the non-expert. Especially after grinding with P400 and P1200, the expert was more than four times slower than the non-expert.

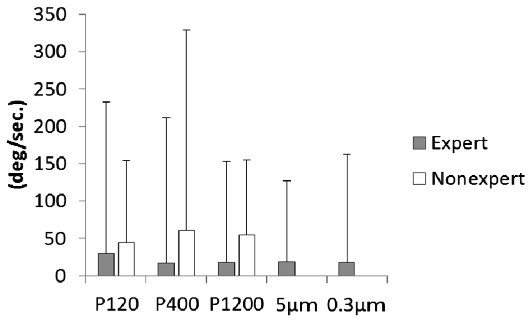

Fig. 6. The speed of the subjects' left eyeball movement while observing the polished surface

3.6 The Amount of Time the Subjects Closely Observed with their Left Eye While Inspecting the Polished Surface

Figure 7 shows the amount of time the subjects closely observed with their left eye while observing the polished surface. The expert's length of time with SiC grinding with P120, P400 and P1200 was longer than that of the non-expert.

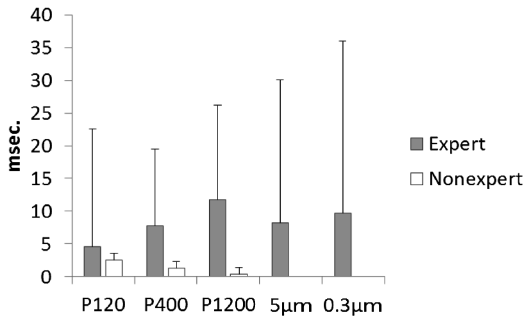

Fig. 7. The amount of time the subjects closely observed with their left eye

3.7 The Characteristics of the Eyeball Movements While Inspecting the Polished Surface

Figure 8 shows the characteristics of the eyeball movements of the subjects while inspecting the polished surface. When inspecting the polished surface, the expert maintained greater distance from the object than the non-expert and kept his gaze steady. Furthermore, the expert tilted the sample to change the angle of the lighting as he inspected. When asked about this, the expert responded that he was looking at the overall balance of the scratches at different angles, rather than confirming each scratch. The non-expert, on the other hand, kept the object closer, his gaze moving about as he inspected. When asked about this, the non-expert responded that he was checking to see the scratches from the previous sandpaper, but wasn't looking for the overall balance.

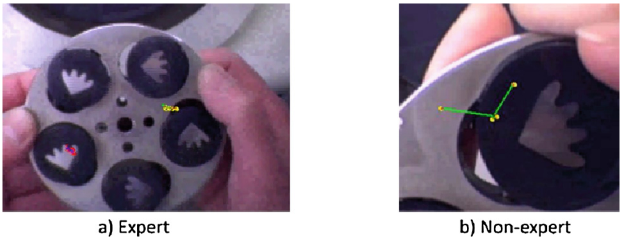

Fig. 8. The characteristics of the eyeball movements of the subjects while inspecting the polished surface.

3.8 The Roughness (RMAX) of the Final Average Finish

Figure 9 shows the roughness (RMAX) of the final average finish of the subjects' works – four places on the tooth surface, three places on the dedendum. The average roughness of the expert's work was 1.12 micrometers, whereas that of the non-expert was 2.34 micrometers. The results of t-test show that the expert's finish was significantly less rough ($p < 0.05$).

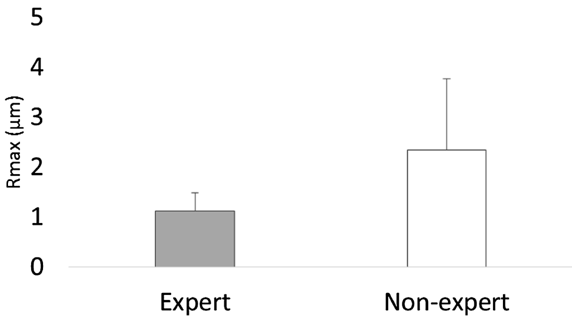

Fig. 9. The roughness (RMAX) of the final average finish of the subjects' works

4 Discussion

Figure 10 shows the flow chart showing the characteristic of subject's grinding work. What was characteristic about the expert's grinding and polishing work was that immediately after he began operating the grinding machine, his hand was on the handle, gradually increasing pressure. Furthermore, during that time, the expert's gaze went back and forth between the handle and the grinding board as he checked on the rotation of the holder, which affixes the sample in place, and the water flow during wet grinding. When asked about this, the expert explained that he was making sure the holder was rotating smoothly, while also listening to the sound the grinding machine was making and gradually increasing the pressure, trying not to cause deep scratches in the unpolished surface. The sound generated during grinding work, other than the grinding noise, is that of the bearing or the motor. We believe the expert was listening to the vibrating and grinding sounds of the machine and adjusting his work accordingly. As a result, cutting by polishing grains was done evenly to create a finish with little roughness and inconsistency.

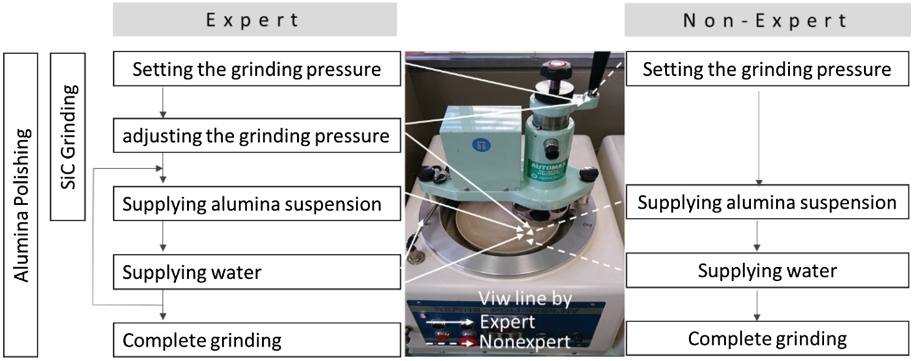

Fig. 10. Flow chart showing the characteristic of subject's grinding work

On the other hand, the non-expert's gaze at the handle was for setting purposes only, and he chose a higher pressure setting than the expert did. He didn't look for any feeling of resistance from the handle, nor listen to the sound generated from the grinding, nor observe the rotation of the holder to see if it would pick up speed then slow down. While the non-expert was aware of the fact that a higher pressure setting would cause deeper scratches or tilt the grinding surface and leave large scratches on the finish, he lacked the ability to make adjustments. As a result, the polishing grains left deep grooves on the surface, and the friction from the grinding generated resistance that caused the rotation speed of the holder to seesaw between acceleration and deceleration. As the holder continued its fast/slow rotation, the resin with its low level of hardness, and the pearlite in the metal areas were deeply scratched, but not the hard martensite layer on the surface of the metal, which made for a rougher and inconsistent finish compared with the expert's.

Furthermore, what was interesting about the expert's gaze while working with 5 and .3 micrometers of alumina is that after he adjusted the pressure, his eyes were mainly on the polishing rotation board. We think that the expert was observing whether the alumina suspension would blacken as a result of the black epoxy getting shaved by the alumina because the test fragment was being impacted. Concluding that an increase in the blackness of the alumina suspension was evidence of effective alumina polishing, after the black color in the suspension liquid increased, the expert added water to clean the top of the polishing board. Seeing the black color of the epoxy mixing with the alumina suspension due to friction, the expert thought that the surface would get big scratches. That is why, after the suspension liquid darkened considerably, he added water and after that, additional alumina suspension. The non-expert, on the other hand, was watching the polishing board and elsewhere, but without checking in on whether the epoxy, which was eroding due to friction, would mix right into the alumina suspension.

Also, what was notable about the expert's gaze while observing the polished surface was that his eyes barely moved and that he inspected the surface as he tilted it. Because of this, we believe, the amount of time the expert spent looking at the specimen was longer than that of the non-expert. By tilting the surface of the specimen to change the angle of the light's reflection and reveal the scratches, the expert was looking for evenness in the overall unpolished surface. The expert's concern was dealing with the scratches that materialized during the cutting of the specimen, erasing scratches that were created two steps before the final polishing process and to confirm that the scratches from the just-completed abrasion showed up in a well-balanced way on the surface. The non-expert was only concerned about the scratches that occurred during cutting the specimen and whether there were scratches left over from two steps back. The non-expert was poring over the entire surface, moving his eyes to check every single scratch. As a result, the speed of the non-expert's eyeball movement was faster than that of the expert, and he spent a shorter amount of time looking.

5 Conclusion

In this research, we observed the way an expert and non-expert performed polishing work on a metal testing specimen and compared their eye movements and their actual polishing motions. And the results show: (1) while performing the polish, the expert made pressure adjustments in considering with the rotation rate of specimen holder, the sound of polishing machine, and the flow of water. On the other hand, the non-expert lacked the ability to make pressure adjustments and left it at the same setting; (2) during alumina polishing, the expert cleaned the surface and supplied alumina as needed, anticipating that the eroded epoxy would mix into the suspension liquid.; (3) the expert's method of studying the unpolished surface involved not moving his gaze, tilting the specimen to observe the surface under changing light. Furthermore, the expert was checking to see, in addition to the amount of scratches present, whether the scratches were scattered across the surface evenly.

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