Analysis of Expert Skills on Handheld Grinding Work for Metallographic Sample

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Abstract. Most common heat treatment process for hardening ferrous alloy is known as carburizing. The quality assurance of carburizing process requires metallographic analysis of case depth, retained austenite, intergranular oxidation, and carbide network by means of metallographic sample. Metallographic preparation consists of sectioning, mounting, plane grinding, polishing to mirror surface, and etching. It is difficult for non-expert to prepare metallographic sample with global mirror surface because preparation skill needs long time experience in this field. There is no study on expert skills in preparation of metallographic samples. In this study, the difference of handheld plane grinding motion of metallographic specimen between expert and non-expert execution was analyzed. For this clarification, an electromyogram (EMG) of the muscle activities between expert and non-expert were investigated. As a result of investigation, we found the clear difference in the muscle activities of triceps, flexor digitorum superficialis, and abductor pollicis brevis between expert and other subjects.

Keywords: grinding, polishing, emg, metallographic preparation.

1 Introduction

Carburizing increases strength and wear resistance by diffusing carbon into the surface of the steel creating a substantially lesser hardness in the core. This treatment is applied to low carbon steels after machining. Usually one or more test specimens used for quality assurance accompany with the heat treatment lot. The quality assurance of carburizing process requires metallographic analysis of case depth, retained austenite, intergranular oxidation, and carbide network with an optical microscope at x 100-1000 magnification by means of the metallographic mounted sample made by the above test specimen.

The preparation process of such metallographic mounted sample is very important for the quality assurance of carburizing process. If the sample edge rounded during the preparation, accurate microstructural information needed for subsurface inspection

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cannot be obtained. Then, it leads the wasting time and money because the re-preparation of metallographic sample is required.

Fig. 1 shows the preparation process of metallographic sample. First, a section is cut perpendicularly from the surface measurement location of the specimen. Second, the obtained specimen was hot-mounted with epoxy resin and then ground by SiC coarse papers with hand to acquire plane surface. Step-wise grinding was then performed in order to produce a flat surface, followed by refined abrasive polishing, to obtain a mirror finish surface by semi-automated polishing machine.

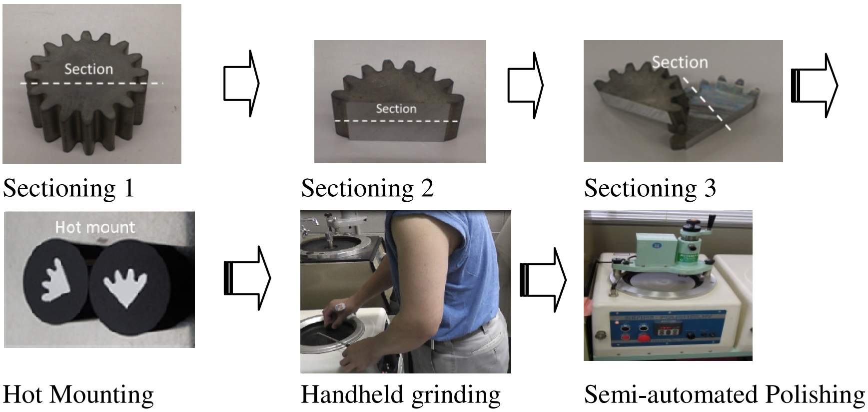

Fig. 1. Preparation process for metallographic sample

The process for the grinding and polishing process is standardized [1]. Polishing techniques for the thermal spray coating is analyzed [2]. Many techniques for polishing process of metallographic process is contained in the technical documents [3-4]. However, most studies have not focused on the expert skills of grinding and polishing process. In fact, the surface finish of metallographic sample differs between expert and non-expert preparation. The resulting measurements of the surface roughness for ground surfaces are shown in Figure 2. Measurements were performed by Surface measurement equipment (Tokyo seimitsu, SJ-301). Rt is Sum of height of the largest profile peak height Rp and the largest profile valley Rv within an evaluation length. The mean of Rt on each gear teeth by the expert was better than that by the non-expert 1, non-expert 2, and beginner. The deviation of Rt by the expert was also better than that by the non-expert 1, non-expert 2, and beginner.

The ground surfaces of the specimen prepared by the expert were more horizontal and more uniform in roughness, making them more ideal. This quantitatively verified the expert’s superior grinding technique, although his skill has been well known to his colleagues for some time.

For the efficient transfer of the skills from expert to non-expert, it is necessary to compare and clarify the difference between the expert and non-expert execution. Comparison of the motion between expert and non-expert is commonly used for the development program for beginner and non-expert.

In this study, we compared and analyzed the differences in hand-held grinding motion and muscular activity for all subjects during the grinding procedure. Motion during the grinding process was measured by electromyography (EMG), and the EMG activity of the upper limb on the dominant arm holding the abrasive was recorded. We then evaluated the differences in grinding motion and muscular activity using the data collected. We hope that this study's results will serve as a useful educational reference for the technical development of metallography technicians.

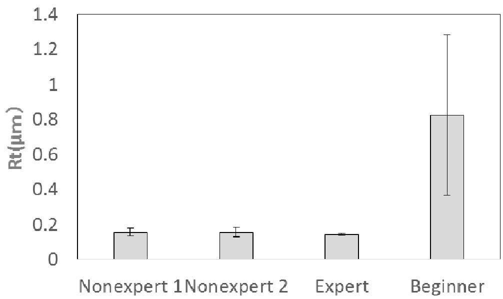

Fig. 2. Surface roughness on final surface finish between subjects

2 Experimental Method

2.1 Subjects

Subjects were 4 males having 20 (Expert), 5(Non-expert 1), 2(Non-expert 2), and 0 (Beginner) year experience in handheld grinding operations respectively.

2.2 Samples to be Ground

Carburized gears for an aircraft component part which is made of 9310 Steel NiCr–Mo alloy (AMS6265) were used as the sample to be ground and polished. These gears were normalized, tempered, carburized, hardened, subzero cooled, and final tempered in the same heat treatment lot. After heat treatment, the specimens were cut into quarters of a gear consisting of four teeth, then hot mounted with epoxy (Durofast, Struers, an epoxy resin with high content of mineral and glass filler).

2.3 Grinding Machine

One grinding machine (Refine Tec Ltd, STO-228B) was used for the experiment. This machine has one rotating table. This grinding machine is usually used for the preparation of metallographic specimens by the subjects. The grit P120 SiC abrasive which was usually used for plane grinding process of carburized gear sample was used for the experiment.

2.4 Motion Analysis Method

To analyze each technician's technique, each subject grasped a specimen for metallographic examination and pressed it down on a rotating disk (300rpm) to grind the surface of the specimen. The activity of the upper limb on the subject's dominant side, which operated the grinder, was recorded from a side view using a digital video camera (HC-V520M, Panasonic) for analysis. In order to measure actual motions and muscle activities during the grinding process, we carried out the recording in synchronization with the EMG and behavior measurements.

2.5 Electromyographic Measurement System

Electromyography analysis was conducted using an EMG multi-channel telemeter system WEB-1000 (NIHON KOHDEN CORPORATION). The sampling frequency rate was fixed at 1000Hz and the data loaded into computer via A/D converter for analysis. In order to evaluate the relationship between hand and upper limb while holding a metallographic sample, we attached EMG markers at eight positions: on the middle fibers of the deltoid (D), the pectoralis major (PM), the biceps brachii (BB), the triceps brachii (T), the extensor carpi radialis brevis (ECRB), the flexor digitorum superficialis (FDS), the abductor pollicis brevis (APB), and the 1st dorsales interossei muscles (1/D) as shown in figure 3. The grinding motion, conducted in 5 seconds for three times, was subject to EMG waveform analysis.

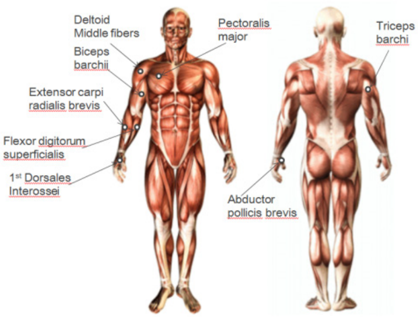

Fig. 3. The measured muscle

2.6 Data Analysis

Average Rectified Value of EMG (mVsec) during the three plane grinding motions for 5 seconds was calculated. The above mean value (mVsec) was divided by the EMG value (mVsec) corresponding to each muscle during the rest on each subject.

3 Results

3.1 Characteristics in Motions

During the expert technician's session, the movements of the elbow joint, figure joints and maniphalanx were hardly seen against the rotational force of the disc while he was grinding the specimen under the rotational load of the grinding disc. Slight adduction and abduction on the shoulder joints was observed, but his upper limb was generally stabilized. His hand and maniphalanx were in the functional positions of the intrinsic muscles. He grasped the metallographic specimen at four points, using his thumb, index finger, middle finger and ring finger to press down on the rotating disk. As to the details of each finger position when holding the specimen, the CM joint on thumb was in the palmar abduction position, the MP and IP joints were extended, the MP joint on the index finger was flexed, the PIP joint was slightly flexed, and DIP joint was extended. The MP joint of the middle finger was slightly extended, and the PIP and DIP joints were slightly flexed.

For non-expert subject 1, we observed adduction and abduction on the shoulder joint. His elbow joint flexed and fluctuated widely. As he put strength into his fingertips to press the specimen against the rotating disk, his finger joints were dorsally extended.

For non-expert subject 2, we observed only abduction on the shoulder joint. When he pressed down the specimen on the rotating disk, his body core tilted and his elbow joint flexed. As he put strength into his fingertips to press the specimen against the rotating disk, his finger joints were dorsally extended.

For the beginner, we observed abduction on his shoulder joint. When he pressed down the specimen on the rotating disk, his body core tilted and his elbow joint flexed. As he put strength into his fingertips to press the specimen against the rotating disk, his elbow and finger joints fluctuated, and his finger joints were dorsally extended.

3.2 The Muscle Activity Pattern

Figure 4 shows the EMG muscle activity on each subject during grinding motion.

Deltoid. We observed an increase in D muscular activity for non-expert 1, which was sustained throughout the trial. Non-expert 2 showed a slight increasing and decreasing pattern, although his rate of increase in muscular activity was lower than non-expert 1. The muscular activity of the expert showed a constant pattern, which was lower than other subjects. The beginner showed a constant muscular activity pattern, but it tended to increase slightly more than the expert's did.

Pectoralis Major. All subjects except the beginner displayed a constant pattern without increase in activity. The beginner showed a constant pattern.

Biceps Brachii. Non-expert 1 showed a constant pattern. Non-expert 2 showed an unstable pattern with high activity. The expert showed a stable pattern without increase in activity. The beginner displayed a pattern with high activity similar to non-expert 2.

Triceps Brachii. Non-expert 1 displayed an unstable pattern with increases in activity. Non-expert 2 showed a pattern with decreasing activity in the first half, and increasing activity in the last half. The expert showed a constantly active pattern. The beginner showed no increase in activity.

Extensor Carpi Radialis Brevis. Non-expert 1 showed a constant pattern of high activity. Non-expert 2 showed a decrease in activity in the first half, an increase in activity in the middle, and a final decrease at the end of the trial. The expert showed a stable pattern without increase in activity. The beginner showed a constantly increasing pattern, similar to that displayed by non-expert 2.

Flexor Digitorum Superficialis. Non-expert 1 showed a constant pattern. Non-expert 2 showed a gradually increasing pattern but without significant increase in activity. The expert showed a stable and constant pattern. The beginner displayed a pattern of slight increases, but not to the same extent as the other subjects.

1st Dorales Interossei Muscle. Non-expert 1 showed an unstable pattern in muscular activity, which fluctuated slightly. Non-expert 2 showed a decrease in activity in the first half, an increase in activity in the middle, and a final decrease at the end of the trial. The expert showed a stable pattern without significant increase in activity. The beginner showed a constantly active pattern without significant increase in activity.

Abductor Pollicis Brevis. Non-expert 1 showed a pattern with increasing activity at the beginning of operation and decreasing activity during operation. Non-expert 2 showed a constant pattern without increase in activity. The expert showed a significant increase in activity at the beginning of operation, and then a decrease in activity. The increase in activity was higher for the expert than for other subjects. The beginner's pattern decreased at first and then stabilized.

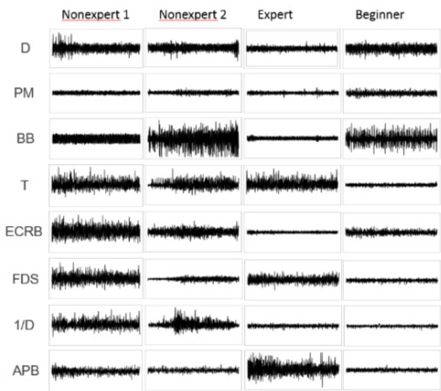

Fig. 4. The EMG during Grinding motion

3.3 Muscle Activity Relative Value

In order to calculate the amount of muscular activity during grinding, we assumed an EMG integrated value of each muscle at rest in a sitting position as 100%. The measurements described below are relative to this baseline, and are calculated using the EMG readings for each subject to allow us to compare the amount of muscular activity more easily. (Figure 5).

In non-expert 1, we observed the following levels of muscular activity. 119% for D, 158% for PM, 309% for BB, 1002% for T, 881% for ECRB, 1099% for FDS, 1479% for 1/D, and 1296% for APB. Non-expert 1 also showed a slightly increase in muscle activity for the D, PM and BB. However, he showed a significant increase in muscular activity for the T, ECRB, FDS, 1/D, and APB.

In non-expert 2, we observed the following levels of muscular activity. 232% for D, 237% for PM, 371% for BB, 666% for T, 331% for ECRB, 479% for FDS, 719% for 1/D, and 270% for APB. He showed a tendency towards increased activity in each muscle when compared to his resting state, especially for the T and 1/D.

In the expert technician, we observed the following levels of muscular activity. 113% for D, 111% for PM, 121% for BB, 419% for T, 132% for ECRB, 1083% for FDS, 330% for 1/D, and 1240% for APB. Compared to other subjects, the expert displayed less muscular activity for the D, PM, BB and ECRB. More significant increases in activity were observed for the FDS and APB. We also observed a tendency towards increased activity for the T, but it was less than the increases shown for the FDS and APB.

The beginner displayed the following levels of muscular activity. 174% for D, 200% for PM, 312% for BB, 203% for T, 343% for ECRB, 414% for FDS, 704% for 1/D and 340% for APB. Only the 1/D muscle showed an increase in activity, and the increased activity levels of other muscles were generally lower than other subjects.

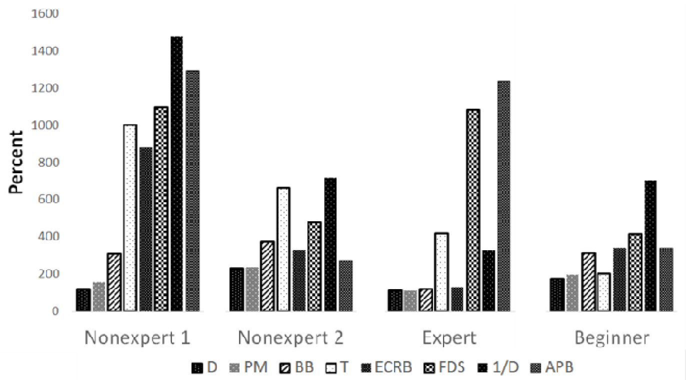

Fig. 5. The relative value of integrated electromyography between subjects

3.4 The Average EMG during Grinding Motion

The muscular activity of each subject was observed for the duration of the grinding operation. The data was normalized with the time axis at 100% and smoothed for comparison analysis as shown in Figure 6.

Deltoid. The data for the expert was more consistent, and shows a significantly low value compared to the other subjects. Both non-experts 1 and 2 showed unstable activity, which did not indicate a consistent value.

Pectoralis Major. All subjects exhibited similar values. However, the values for the expert and non-expert 1 were more stable and consistent than the values for non-expert 2 and the beginner.

Biceps Brachii. The expert's readings showed a constant and stable level of activity, which was significantly lower than other subjects'. Non-expert 1 and the beginner showed more activity in comparison with the expert, while non-expert 2 showed inconstant and unstable levels.

Triceps Brachii. The expert displayed a consistent and stable level of activity. Non-expert 1 has similar data to the expert, while non-expert 2 had a more inconsistent and unstable level of activity. The beginner had the lowest level of activity.

Extensor Carpi Radialis Brevis. The expert showed a constant and significantly low level of activity. The beginner showed a tendency towards increase compared to the expert. Non-expert 1 showed inconstant and unstable activity. Non-expert 2 showed a significant increase in activity compared to other subjects.

Flexor Digitorum Superficialis. The expert showed a stable and increased level of activity compared to the non-experts and the beginner. Non-expert 1 showed a greater increase in activity than other subjects.

Interossei Dorsales Muscle. The expert showed a low level of activity, as did the beginner. Non-expert 1 showed a high level of activity. Non-expert 2 was unstable, shifting from low to high levels of activity.

Abductor Pollicis Brevis. The expert showed a significant increase in activity compared to other subjects. He showed an increase in activity at the beginning of operation and a slight decrease just before the end of operation. The other subjects showed similarly low rates, but unlike the expert, they showed a more constant level of activity.

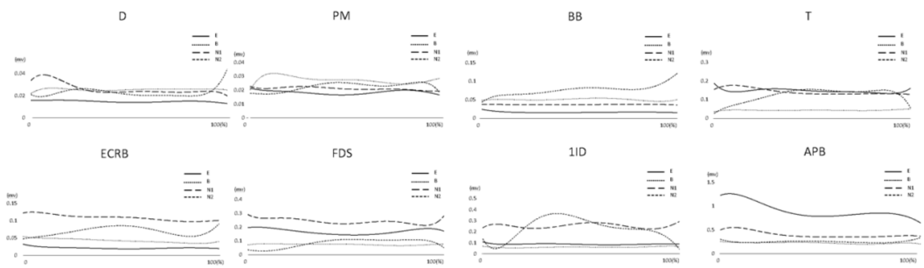

Fig. 6. The average EMG on each muscle during Grinding motion

Based on the analysis of the expert, we observed a constant increase in activity for the T, FDS and APB. The other muscles sustained constant activity without any significant increase. In contrast, non-expert 1 showed a difference in muscular activity patterns for the BB, D, T, ECRB, FDS and 1/D. He showed unstable activity patterns for the D, BB, ECRB, FDS and 1/D, while the expert showed a constant pattern in these muscles' activities. Although non-expert 1 showed no significant increase in activity for the APB, the expert showed a significant increase in activity, totally opposite the result from non-expert 1.

Non-expert 2 showed a slightly increasing tendency in muscle activity for the T, ECRB, FDS and 1/D. He showed a significant increase in activity for the BB, but no increase in activity for the APB. These results were also different from the expert. The BB and T, which provide for elbow joint movement, moved simultaneously. The muscles related to the finger joints and maniphalanx showed changes in activity different to the expert's pattern. The beginner showed an increase in muscular activity of the D and BB. This pattern was not observed for the expert.

As the results shows, the muscle activities of elbow joints, finger joints and maniphalanx of the expert showed a reciprocal relationship of agonist muscle and antagonist muscle. The data verified that his muscular activity pattern included no simultaneous activity resembling that observed in the other subjects. The activity patterns observed in other subjects differed significantly from that of the expert. The muscular activity of the expert for the BB and APB showed a definite difference compared to the other subjects.

4 Discussions

Compared to the other subjects, the expert's patterns displayed certain significant characteristics. The characteristics observed involved the T functioning as the extension muscle of the elbow joints, the FDS functioning to manipulate the finger joints and maniphalanx, and the abductor pollicis brevis influencing the maniphalanx. Those muscles related to the maniphalanx, elbow joints and finger joints were well coordinated, with balanced activity of the agonist muscle and antagonist muscle. Similarly to the T, the APB showed an increase in activity. We suggest that the muscular activity of the T increased so strongly because the expert strongly grasped the specimen to stabilize it and press it down on the rotating disk.With regards to the ECRB and FDS, the activity of the ECRB decreased, but the activity of the FDS increased. It is suggested that these muscles provide a strong grasp of the specimen and stabilize the subject's grip. These muscles also work to stabilize the finger joints in volar flexion. Grasping an object mainly uses the intrinsic muscles, including the interossei and lumbricales. When more strength is required, extrinsic muscles provide further stability for the maniphalanx. The result suggests that the FDS showed more activity when strong force was required to press the specimen down on the rotating disc.

To press the specimen effectively, the finger joints are set in the volar flexion position to activate the intrinsic muscles. This is known as Tenodesis grasp. Therefore, we observed increases in the activity patterns of the volar flexion muscles of the finger joints, including the flexor digitorum superficialis, and decreases in the muscular activity patterns for the finger joints and dorsal extension muscles, including the ECRB. This reciprocal relationship can be acknowledged for the 1/D and APB. Since the 1/D affects the MP joints in flexion position and the PIP and DIP joints in extension position, we expected an increase in the activity patterns in this study, but activity actually decreased, contrary to our expectations. This suggests that the thumb functions more than the index finger when grasping a specimen. While pressing the specimen down on the grinding disk, both muscles were activated. However, it was presumed that the expert took advantage of the thumb to stabilize and pressed down strongly. The 1/D functions in regular grasping motions, which accounts for the increase in 1/D activity observed for other subjects, but the expert took advantage of the function of APB to provide a more effective grasp. One more difference observed was that the expert showed no function of the BB compared to other subjects. This was greatly different from the other subjects. Since the other subjects held the scapulohumeral joints in the abduction position, when their upper limb was pulled in the abduction direction by the rotating force of the grinding disc, they attempted to use the BB to hold their elbow joints in the flexion position.

Moreover, the expert showed a low activity rate for deltoid-related shoulder joints in comparison with the other subjects. This suggests that the expert pressed the specimen down on the grinding disc using only his elbow joints, finger joints and maniphalanx, without fixing his shoulder joints. In comparison, the coordination in agonist and antagonist muscles observed in the expert was not detected in the other subjects. The upper limbs are generally stabilized by the function of the proximal shoulder joints. However, the other subjects used their deltoid muscles to fix their shoulder joints. This action was not observed in the expert. Also, the expert showed no significant increase in activity compared to his resting state. This result suggests that the expert applied pressure by effectively controlling the muscles affecting his elbow, finger joints, and maniphalanx without fixing his shoulder joints. However, the other subjects displayed simultaneous action of agonist muscle and antagonist muscle, coupled with a decrease in muscular activity, which strongly opposes the behavior exhibited by the expert.

Moreover, the expert kept his body core upright and maintained the position of his upper limb adequately. The other subjects were more strongly affected by the rotating force of the grinding disc, and so failed to keep their upper limbs stable, which caused their body core and elbow joints to be in flexion positions. This evidence suggests that the expert relaxed the tension of his shoulder to a certain extent, and pressed down the abrasive without using excessive force. In contrast, the other subjects opened their sides, and could not effectively transfer adequate force to the abrasive. Thus, no coordination in muscular activity was observed in other subjects.

The expert showed a greater amount of muscular activity in the T, FDS, and APB compared to other muscles. This result suggests an increase in muscular activity. The different correlation between each joint observed in the expert was not detected in the muscular activity of the other subjects. This suggests that the non-experts maintained an effective grinding position, but they ineffectively pressed down the specimen with brute force, lacking either sufficient function to press down or effective function of the anterior upper limb muscles. This evidence verifies that the expert effectively pressed down the specimen on the rotating disk in accordance with the rotating movement. This behavior led to the difference in the muscular activity pattern and amount of action seen. An educational reference for the training of beginner and non-expert technicians is under preparation. Thanks to this study, we added the useful instruction of, "shoulder down and extend elbow joints," to the training materials.

We investigated about the feature of "Grinding" motion and work disorder by using surface electromyography. In this study, we investigated the feature of the "Grinding" motion by using a metallographic sample with different of its surface.

The muscular function is different by the muscular shape and the muscle contraction property. In this study, it is showed two muscle activity types of muscles activity increased with motion and continuous muscle activity patterns with "Grinding". It is showed coordinated muscle patterns with "Grinding". The features of expert's body movement during "Grinding" are upright trunk to forward keeping his upper arm extension position and intrinsic position of hand. But Non-experts' body movement during "Grinding" are trunk was round back, elbow flexion and fingers flexed.

Deltoid is a prime mover for nearly all movements of the shoulder. The deltoid also plays an important role in stabilizing the shoulder. It is a powerful abductor. Pectoralis Major is a powerful chest muscle responsible for movements in front of the body, such as pushing, reaching, throwing et al. This feature maintains the leverage of the different fibers in the various positions possible in the shoulder. Biceps Brachii is fusiform shape and multijoint function limit its mechanical advantage compared with powerhouse synergists other muscle, which have pinnate fiber muscles. Triceps is a strongest function it is extension of elbow joint, which is accomplished by all fibers of the muscle. Extensor Carpi Radialis Brevis works closely to extend the wrist. This muscle also radially deviates the wrist. Flexor Digitrum Superficialis is particularly strong in this function when the wrist is fixation and fingers flexion. 1st Dorsal Interosseous and Abdunctor Pollicis Brevis works MP joint flexion, PIP joint and DIP joint extension when take a pinch material.

5 Conclusions

In this study, we examined the muscular activity of technicians when grinding specimens for metallographic testing. The results revealed significant differences between subjects in increases in muscular activity for the T, FDS, and APB, and in the amount of muscular activity for other muscles. These results verify that the T, FDS, and APB are likely connected with the grinding action. When comparing the expert's muscular activity with that of other subjects, we found no noticeable difference in activity for the T, FDS and APB.

References

1. ASTM International, Standard Guide for Preparation of Metallographic Specimens, E3 - 2011 (2011)
2. Smith, M.F.: A Comparison of Techniques for the metallographic Preparation of Thermal Sprayed Samples. Journal of Thermal Spray Technology, 287–294 (1993)
3. Vander, G.F.: Metallography: Principles and Practices. ASM International (1984)
4. Samuels, L.E.: Metallographic Polishing by Mechanical Methods. ASM International (2003)