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Ti Microholes Potential for Thermal Power Plants Application Punched by WC/Co Micropunch

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Abstract

The use of microholes is a potential approach to enhance fluid flow and heat exchange within thermal power plants, especially for the turbines. Ascribed to eco environmental competition, micropunching is extremely suitable for the mass production of micro features with friendly eco effects. Therefore, the morphology variation of micropunch and microhole during the punching with WC/Co micropunches was investigated by scanning electron microscopy (SEM), energy dispersive spectrometer (EDS) and confocal laser. Results reveal that due to the optimal joint contribution of WC and Co, the formed microholes satisfy with the practical requirements in the quasi stable period. Moreover, the serious wear of micropunch occurs with the wear loss both of Co and WC when the punching number exceeds 1525. With the further increment in punching numbers, the dominant factors of the wear loss would mainly rely on the easily peeled off WC due to the serious loss of Co. In addition, the microholes can be adequately processed after about 30 min by natural sand grains. The quality of the hole would decrease with further increase in processing time and sand accumulation becomes severe.

Keywords: microhole, thermal power plants, WC/Co, micropunch, morphology

1. Introduction

It is well known that the thermal power plants can be classified by the source of the energy used to generate the steam that it is expanded in the turbine to produce electricity, which are listed as follows classified by heat source: (1) heat sources for fossil fuel power stations: (i) a steam turbine generator and (ii) the natural gas-fired plants. They may use a combustion turbine. To date, a coal-fired power station produces heat by burning coal in a steam boiler. The steam drives a steam turbine coupled to a generator producing electricity. It is well known that the fossil fuel power stations are still currently the dominating plants for generation

of energy production around the world. (2) A nuclear power plant is a steam turbine plant where the steam is generated by a nuclear reactor. Up to now, about 10% of all electric generation worldwide is produced by nuclear power plants. It should be noted that after the Fukushima disaster, all the plants are scheduled to be shut down in a few years, and the rest of the world is very hesitant with respect to what role nuclear energy should have in future energy planning. (3) Geothermal power plants use steam extracted from hot underground rocks. This kind of energy plant only contributes a minor energy output compared with the global demand. (4) Biomass-fueled power plants are fueled with wood pellets, wood chips, straw and waste from the agricultural industry such as sugar cane and nut scale, municipal solid waste, landfill methane or other forms of bio gas. (5) In integrated steel mills, blast furnace exhaust gas is a low cost, although low energy-density, fuel. This recycled gas is available to produce about 60% of the total electricity consumption. (6) Waste heat from industrial processes is occasionally concentrated enough to use for power generation, usually in a steam boiler and turbine. (7) Solar thermal electric plants use sunlight to boil water and produce steam, which turns the generator. (8) IGCC (integrated gasification combined cycle) with carbon capture and storage (CCS) technology allows coal to be used to generate power as cleanly as natural gas [1, 2].

In most of the countries, thermal power plants are playing an important role in the energy production. Therefore, the research work should be taken enough attention toward the optimization of these power plants. In the developing countries, energy supplies are less secure because of its costlier price. Indeed, there is a need to reconsider lowest cost energy options and the relevant techniques. Since, from an energy performance point of view, first law analysis has been found to be insufficient. So, in thermodynamic analysis of various thermal processes and plant systems, exergy analysis is getting its own importance. It is well known that the total conversion of heat into work is not possible.

Consequently, that part which is available for conversion is termed as exergy. It is a property associated with the state of system and environment, nowadays a useful tool to differentiate between internal irreversibility and energy losses in a process [2]. Thermal power plant performance can be evaluated through energetic performance criteria, which are electrical power and thermal efficiency. In recent decades, exergy analysis of plant has been found as a useful method in the design, evaluation, optimization and improvement of thermal power plants [3–5]. Exergy analysis helps in finding the losses taking place in a system. By this method, energy conversion at different points, various component efficiencies and points of largest losses are easily obtainable and hence it helps in taking necessary action to decrease them [6, 7].

Some researchers have contributed review paper on exergy analysis, which helps the young researchers to get in touch with the previous year's problems [8]. In power plants, insights have been provided into various energy and exergy efficiencies which are helpful for design engineers [9, 10]. As a result, improvement in thermal performance of power generation units and consuming devices can be achieved significantly by combining exergy analyses with the related techniques upgraded.

In recent years, microtechnology has become one of the key disciplines with a significant effect on the development of new products and production technologies [11–14].

It is well known that microtechnology describes the technological approach, directed to the miniaturization of components and systems, down to micrometer scale. Microtechnological components, such as distributed holes, bear the potential to provide further functionality, for example, enhancing fluid flow and heat exchange within thermal power plants, especially for the turbine blades [15–18].

Up to now, the ever increasing demand for smaller, higher quality and lower priced products from almost all fields of industry, household equipment and entertainment electronics involves the optimisation of already existing and the development of new manufacturing methods which are tailor-made for the micro systems technique with higher precision [19, 20].

However, these kinds of micro devices are mainly fabricated by using micromachining technique, and fabrication technology with stable and low cost as one of the important issues [11, 12, 14, 19].

Therefore, the microholes formed by micropunching at low cost and in large quantities, applied for thermal power plants application and micro-parts fabrication have been researched. This research aims at investigating the wear characteristics of micropunch (150 μm in diameter) and the morphology variation of microholes formed by punching pure titanium (Ti) in various processing periods to overcome current problems in the micro-metal-forming technology. In the long run, this research can lead to making microholes distributed in the thermal power materials (both non-metals and metals) at low cost and in large quantities with this eco-friendly technique.

2. Experimental materials and procedures

2.1. Experimental material

Micropunch with 75% volume fraction WC particle and 25% volume fraction Co particle of 50 μm mean size, 150 μm in diameter, is shown in **Figure 1**. **Figure 2** shows the surface texture of micropunch. Pure titanium sheet with 200 μm in thickness was used as the substrate.

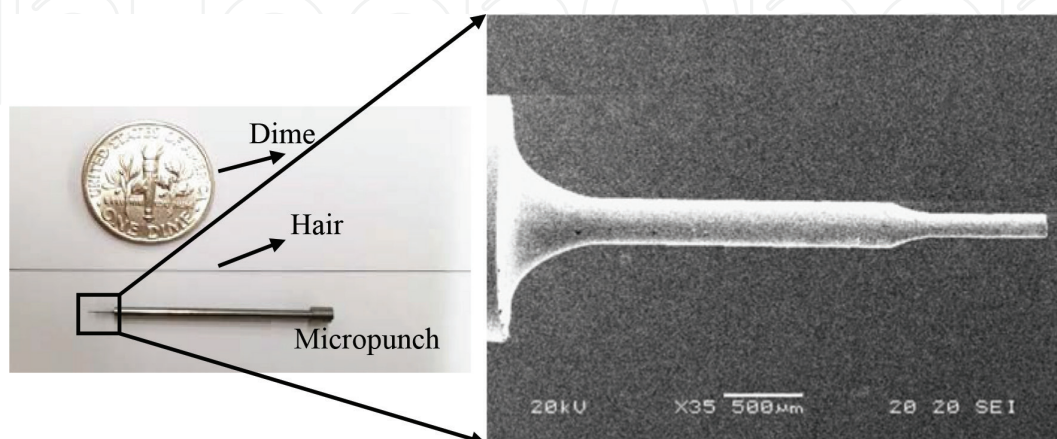


Figure 1. Profile of micropunch.

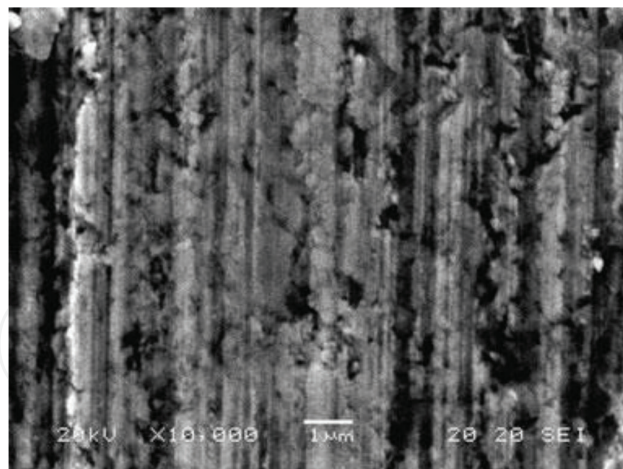


Figure 2. Surface texture of micropunch.

2.2. Experimental procedures

In order to clean the contaminants in the prepared pure titanium sheet, it was carefully washed by acetone and pure ethyl alcohol before putting into the microdie. After that, the microprocessing machine MP50 (made in Japan) was taken to punch the titanium sheet with 20 pulses per minute, and feedrate of 2 mm.

The wear of the micropunch and the variation of the morphology of microholes in different processing periods were investigated using confocal microscopy, scanning electron microscopy (SEM), energy dispersive spectrometer (EDS) and confocal laser.

3. Results and discussion

3.1. Initial wear characteristic of micropunch

The relationship between the wear loss of micropunch and punching numbers is shown in **Figure 3**. It illustrates that the weight of micropunch (each for five times) has an obvious decrease with the increment of punching number in the initial. Its corresponding surface texture is expressed in **Figure 4**. It depicts that the particles distributed more uniformly than that of parent material (cf. **Figures 2 and 4**).

According to **Figures 3 and 4**, it shows that the wear of micropunch in the initial increases significantly, and WC particles cannot be easily observed. Consequently, the dominant factor of the wear loss in the initial period is mainly due to Co. The morphology of the formed microhole is expressed in **Figure 5**. Some substrate debris is distributed sparsely in the back-side as shown in **Figure 5b**, and its EDS results are illustrated in **Figure 6**.

3.2. Quasi stable wear characteristic of micropunch

With the increment of punching numbers, the phenomena of the initial distinct wear of micropunch disappears, the wear loss of the micropunch becomes relatively stable with a little variation

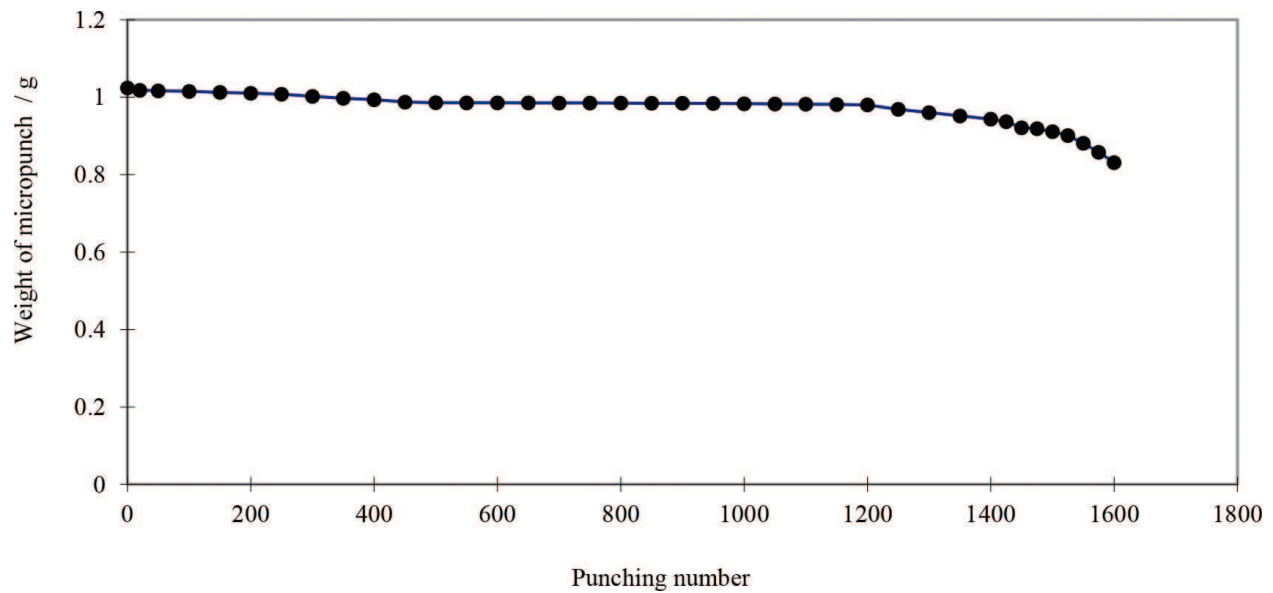


Figure 3. Relationship between wear loss of micropunch and punching numbers.

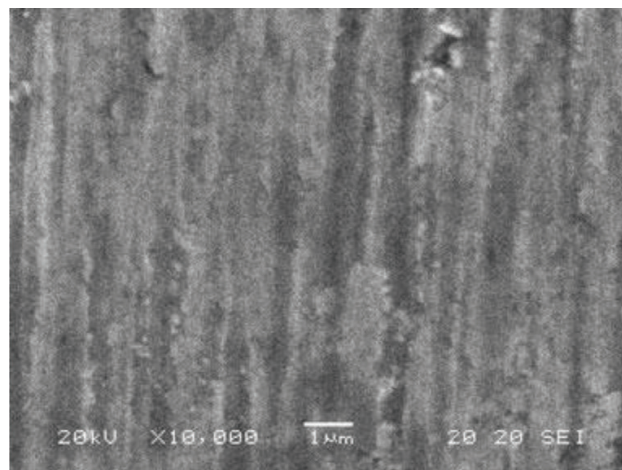


Figure 4. Surface texture of micropunch in the initial condition (punching number lower than 500).

as depicted in **Figure 3**, particularly for punching number from 500 to 1200. The surface texture of micropunch is shown in **Figure 7** correspondingly. It expresses small pieces of WC particles on the surface. Meanwhile, WC particles distribute uniformly on the micropunch surface.

The morphologies of the formed microhole are shown in **Figure 8**. It expresses that although some substrate debris still distribute in the backside (**Figure 8b**), the quality of the quasi stable-period-microhole is definitely superior to the initial period (compared **Figure 5** with **Figure 8**). It illustrates that because of the joint contribution of WC and Co, the wear loss of micropunch in the quasi stable period is little.

3.3. Severe wear characteristic of micropunch

The surface texture of micropunch with punching number over 1525 is shown in **Figure 9**. It shows that large amounts of WC particles distributes on the micropunch surface because of

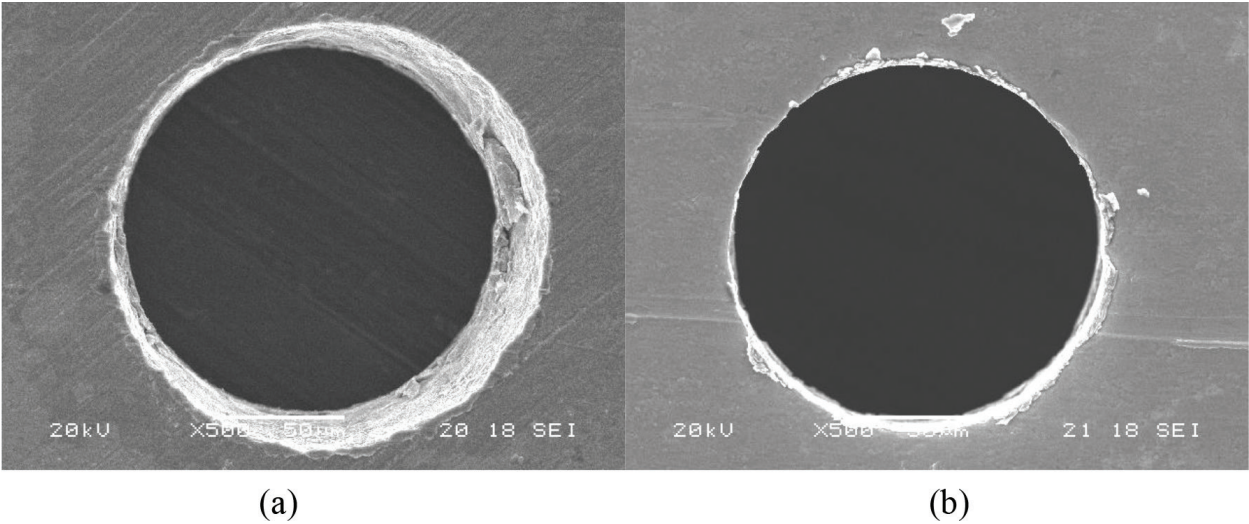


Figure 5. Morphology of microhole. (a) Front side, (b) back side.

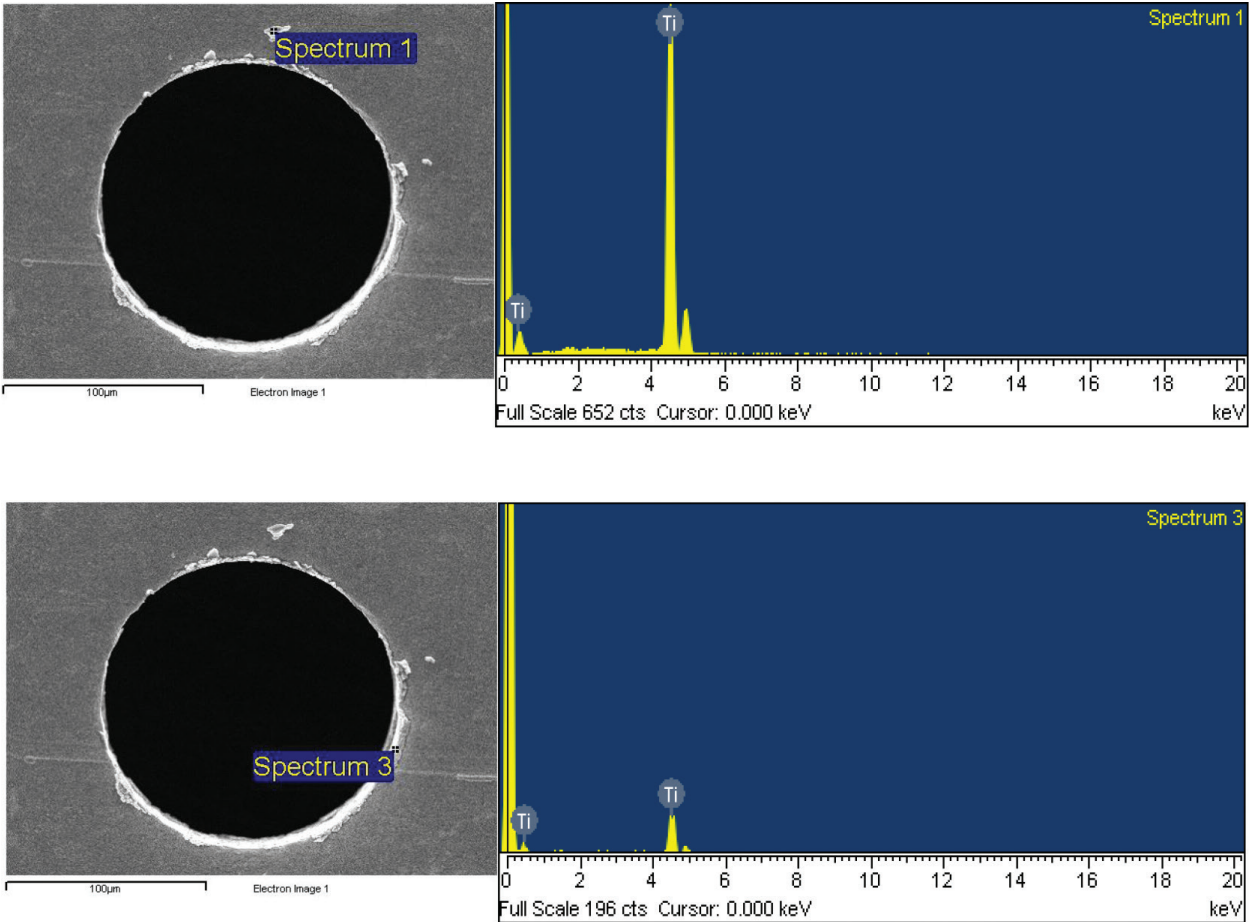


Figure 6. EDS results of debris in the backside.

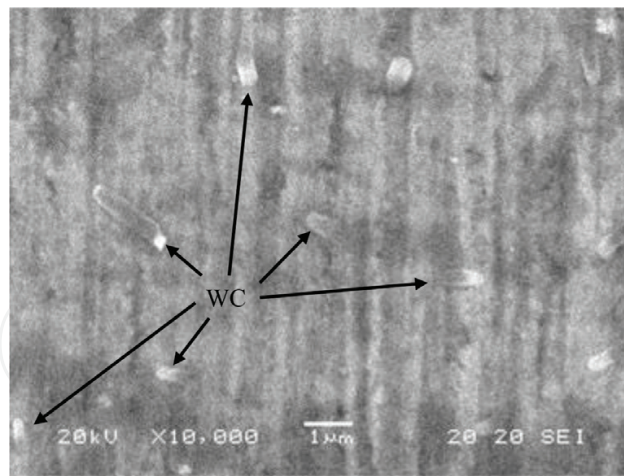


Figure 7. Surface texture of micropunch with punching number between 500 and 1200.

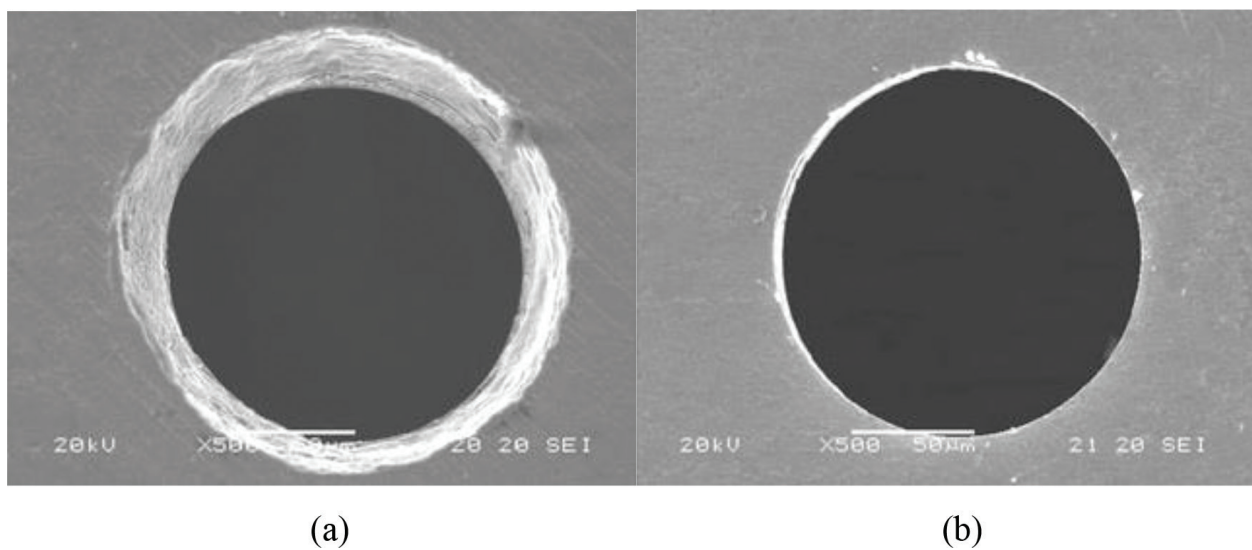


Figure 8. Morphology of microhole. (a) Front side, (b) back side.

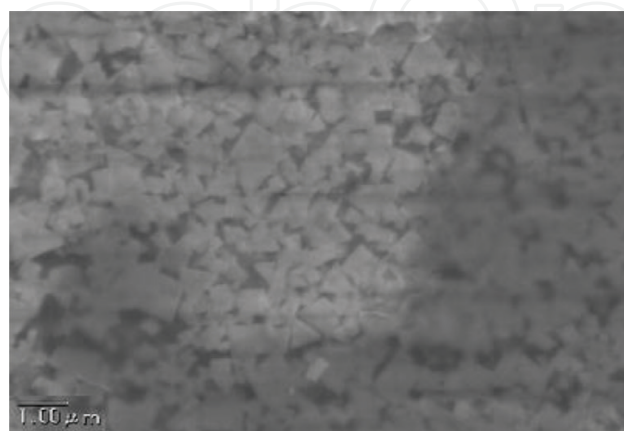


Figure 9. Surface texture of micropunch in the severe wear condition.

serious wear loss of Co, which matches well with **Figure 3**. As a result, the wear of micropunch increases distinctly (**Figure 3**). Furthermore, with the punching numbers increasing further, the dominant factors of the wear loss would mainly rely on WC (which is easily peeled off during the micropunching) as shown in **Figure 9**. Meanwhile, the quality of the machined microhole decreases distinctly (cf. **Figures 5, 8, 10 and 11**). It illustrates that a large amount of micropunch materials are peeled off and adhered to the Ti substrate. At the same time, the substrate material could not be punched successfully and it would stick to the substrate. Also, with the effect of feedrate, the unsuccessfully removed materials would be sheared and form the larger debris as shown in **Figure 11**.

3.4. Profile of the microhole punched by micropunch

The diameter of the punched microhole by micropunch was measured by LEXT confocal laser-OLS3000 as shown in **Figure 12**. Its corresponding results (each for five times) are shown in

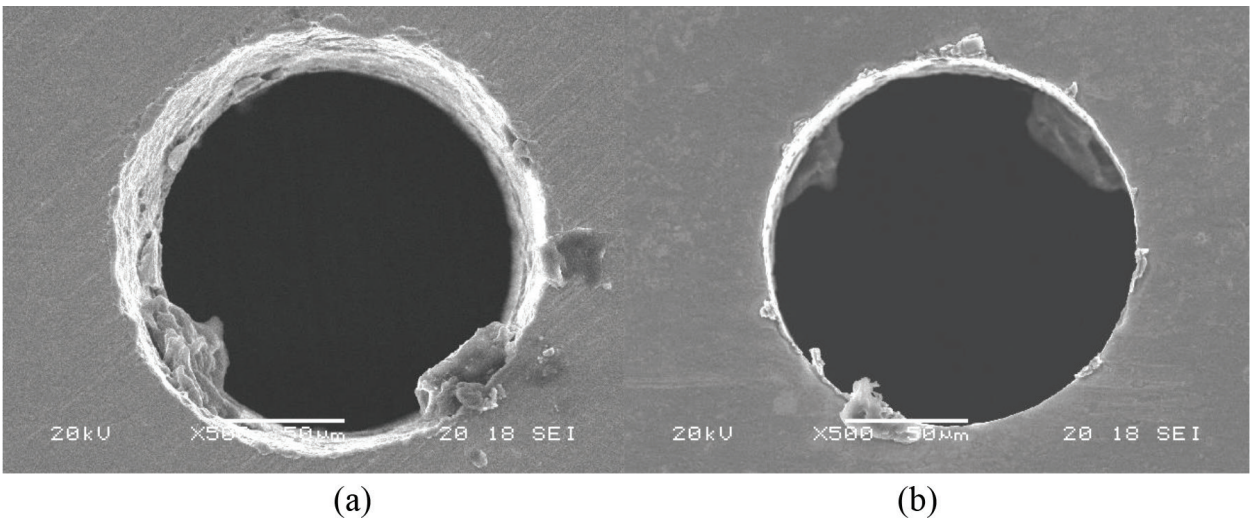


Figure 10. Morphology of microhole in the severe wear condition. (a) Front side, (b) back side.

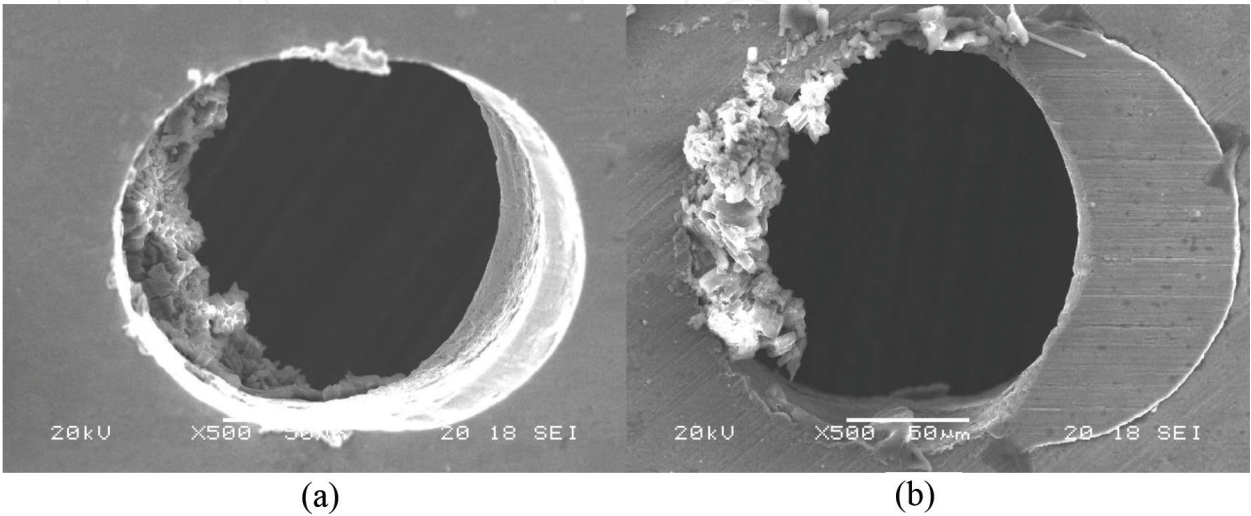


Figure 11. Morphology of microhole in the intensively severe wear condition. (a) Front side, (b) back side.

Figure 13. Compared with **Figure 3**, it indicates that the diameter of microhole changes in the different micropunching periods. At the beginning of the micropunching, the obvious decrement of the diameter of microhole varies with the punching number increasing, which surely matches well with results expressed in **Figure 3**. The attractive results are addressed with the relatively stable diameter of microhole when the micropunching number varies from 500 to 1200. When the punching number increases further, the obvious decrement of the diameter of microhole becomes more and more clear on account of the serious Co loss, especially for the punching number over 1525 as depicted in **Figure 13**. As a result, in the severe wear period of micropunching, due to the serious loss of bonding material Co, the wear of micropunch mainly relies on the easily peeled off WC particles. Simultaneously, because the temperature of the micropunch increases with the increment of the punching number, WC particles are more easily detached off from the micropunch. Consequently, the wear loss of the micropunch becomes more intensive. Furthermore, if the pulses per minute increases, the wear of micropunch will drastically lose. In order to improve the quality of the micropunch, besides the abovementioned, the microstructure of micropunch should be considered further with the composition of the micropunch, especially for the distribution of WC and Co particles.

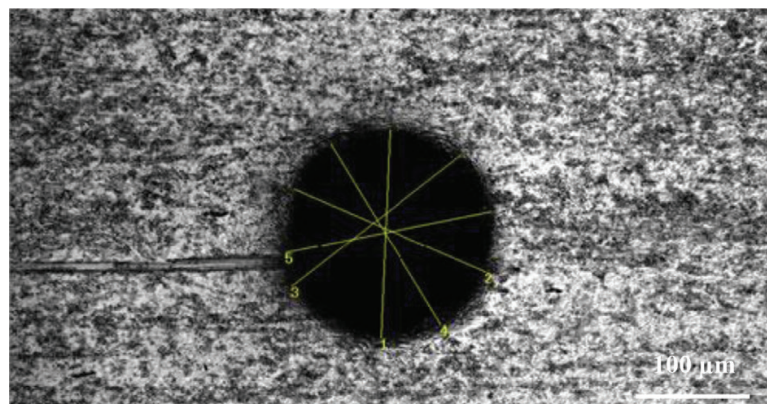


Figure 12. Profile of microhole punched by micropunch measured by OLS3000.

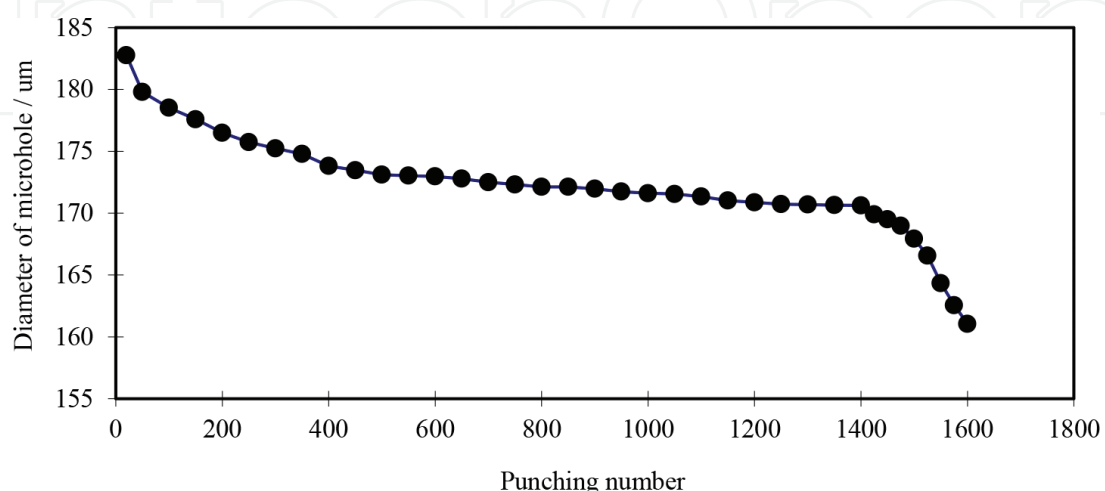


Figure 13. Relationship between diameter of microhole and punching number.

4. Post-treatment for microholes by natural sand grains

Features of microholes (such as **Figures 5** and **8**) in the micropunching include debris (for example, shear marks and burrs). Because of the combination of shear and ductile fracture in the micropunching, the debris produced. Moreover, the property of the processing materials is also one of the crucial effective influence factors on the final features of the microhole. In the meantime, the uniformity of the clearance can affect the microhole features during the micropunching (cf. **Figures 5, 8, 10** and **11**). The debris can hinder the normal functionality of micro features and prevent the proper assembly of micro components to form micro systems. Therefore, the microholes shall be post treated to improve its finishing.

Figure 14 shows the post treated microhole realized with the agitation of abrasive grains through planetary stirring, where natural sand was used as the abrasive due to its environmental

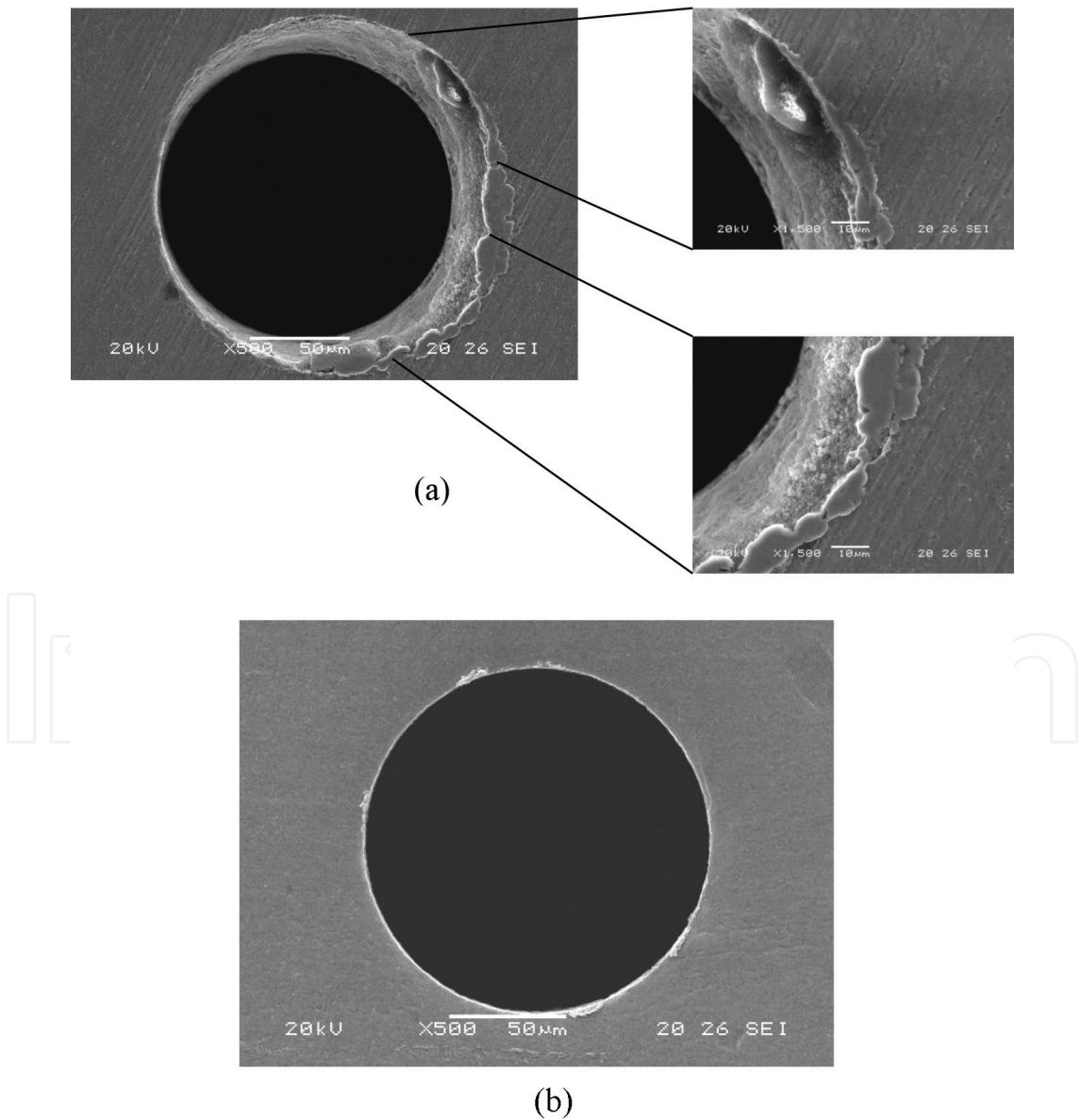


Figure 14. Morphology of a microhole after 20 min processing. (a) Front side, (b) back side.

friendliness. It expresses the results of a 20 min processing microhole. The hole is basically free from loosely attached debris. Burrs at the back side edge are further lowered. Those flattened fragments are slimmer than before. More aggregation of the microscopic grains is observed, both the fragment regions and the edge regions (**Figure 14a**, insets). Their sizes range from the micron to sub-micron. Continued aggregation might possibly be on account of van der Waals or inter-molecular forces.

With further increment of the processing time, the quality of the hole continues to improve. **Figure 15** reveals that the burrs in the back side edge are no longer existed, except for some small isolated pieces (**Figure 15b**, inset). Burrs are protrusions from the edge. Their bonding with the substrate is much stronger than that of the re-attached debris. Tiny burrs are particularly hard to be removed. It is well known that the impact energy from a grain of sand depends on the grain size besides its velocity. Those burrs could not be effectively cleaned by the impact from smaller grains. Yet, the chance that tiny burrs are impacted by the larger sand grains is relatively low.

The fragment terraces on the front side become very thin. As a result, they are noticeable mainly under higher magnification (**Figure 15a**, right inset). In addition, more grains are gathered around the edge of the hole as well as stuck to the inner wall of the hole through attraction forces (**Figure 15a**, left inset).

The quality of the holes cannot improve with further processing. Spontaneously, more sand aggregates after 40 min (**Figure 16**). The attachment of sand grains to the edge regions and inner wall could be visible from the back side as well as from the front side.

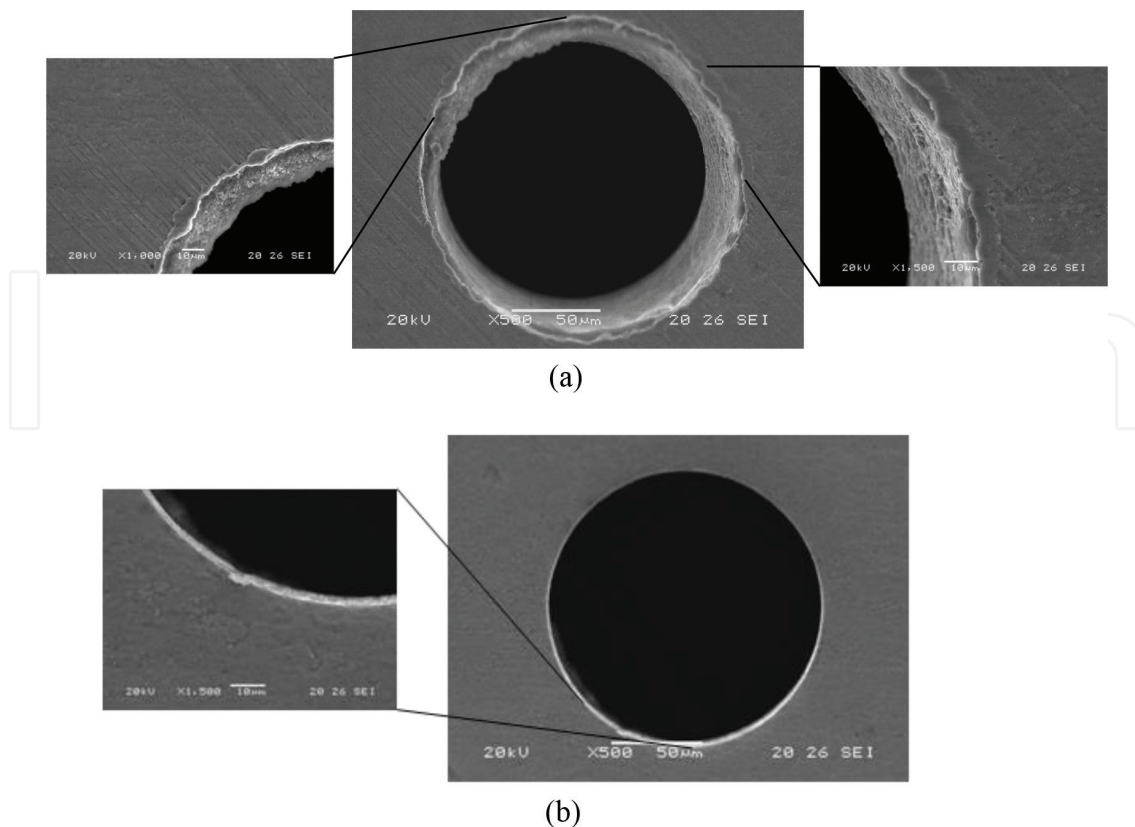


Figure 15. Morphology of a microhole after 30 min processing. (a) Front side, (b) back side.

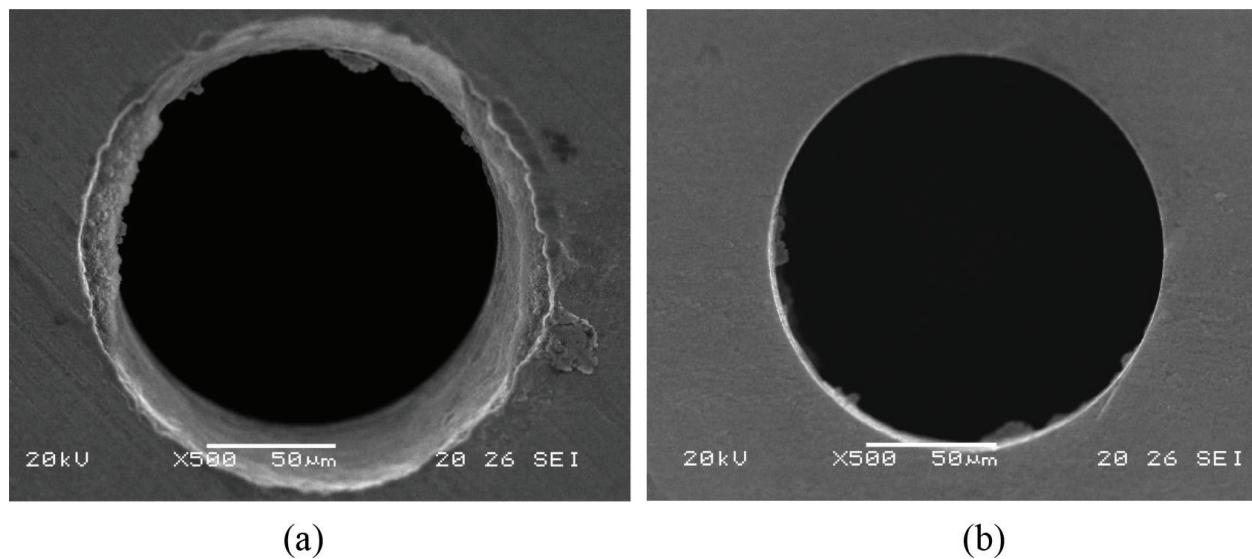


Figure 16. Morphology of a microhole after 40 min processing. (a) Front side, (b) back side.

A band of jagged foil material is detected around the front surface near the edge of the hole. It is mainly produced as substrate material breaks from the punch when it is pulled back from the hole. It cannot be clearly detected before because (1) the feature size is relatively small compared with those fragments detected at earlier times and (2) parts of the band are rolled back against the surface of the substrate material. Apparently sand abrasion could only reduce the width of the band to a few microns. Occasionally, parts of the band are bent toward the microhole. On account of the support of sand gathered underneath, it is unlikely that their posture could be reversed in subsequent processing.

5. Conclusion

The wear characteristic of the WC/Co micropunch used for micromachining microhole potential for thermal power plants application had been researched. It shows that the wear of micropunch increases significantly in the initial and the dominant factor of the wear loss mainly relies on Co. With the punching number increasing, the quasi stable wear of WC/Co micropunch varies with a little wear loss. However, when the punching number exceeds 1525, the serious wear loss of Co and WC of micropunch takes place. Moreover, with the increment of the punching numbers further, the dominant factor of the wear loss would mainly rely on the easily peeled off WC. Meanwhile, the quality of microhole decreases intensively. In addition, the microholes can be adequately processed after about 30 min by natural sand grains. The quality of the hole would decrease with further increase in processing time and sand accumulation becomes severe and no further improvement is observed.

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