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# Effect of Cobalt on Morphology of Microhole Formed by Micropunching

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Kelvii Wei Guo and Hon Yuen Tam

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## Abstract

Due to the trend of miniaturization, the specific advantages of metal forming, especially for the high productivity and material utilization, cannot be exploited to the same extent in the field of electronics production as in conventional metal forming. Because of the competition with less productive and environmentally more polluting technologies, micropunching is extremely suitable for mass production of micro features, and the quality of the relevant punched microholes is definitely attracted to its successful application. Herein, the effect of cobalt on the morphology of microhole formed by punching with tungsten carbide-cobalt (WC/Co) micropunches was investigated. The results reveal that due to the optimal joint-contribution of WC and Co, the morphologies of microholes punched by 75% vol. WC+ 25% vol. Co micropunches not only satisfy with the practical requirements but also the punch using life is at the highest level among the three types of micropunches. Moreover, for 75WC/25Co micropunch, the serious wear of micropunch occurs with the wear loss of Co and WC when the punching number exceeds 1525. With the further increase 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.

**Keywords:** cobalt, micropunch, WC/Co, microhole, morphology

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## 1. Introduction

The demand of miniaturization comes from electronic devices, medical equipment, sensor technology and optoelectronics. Microfabrication technologies play a crucial role in product miniaturization [1–3]. Punching is the process of forcing a punch through the material and into a die to create a hole in the work piece. Micropunching can be an economic way of fabricating shaped microholes in mass production. The ability to fabricate microholes in

large quantities has potential applications in micro-chip packaging, ink-jet print-head manufacture, bio-chip technologies and so on. Work in micropunching was reported by many investigators [4–7].

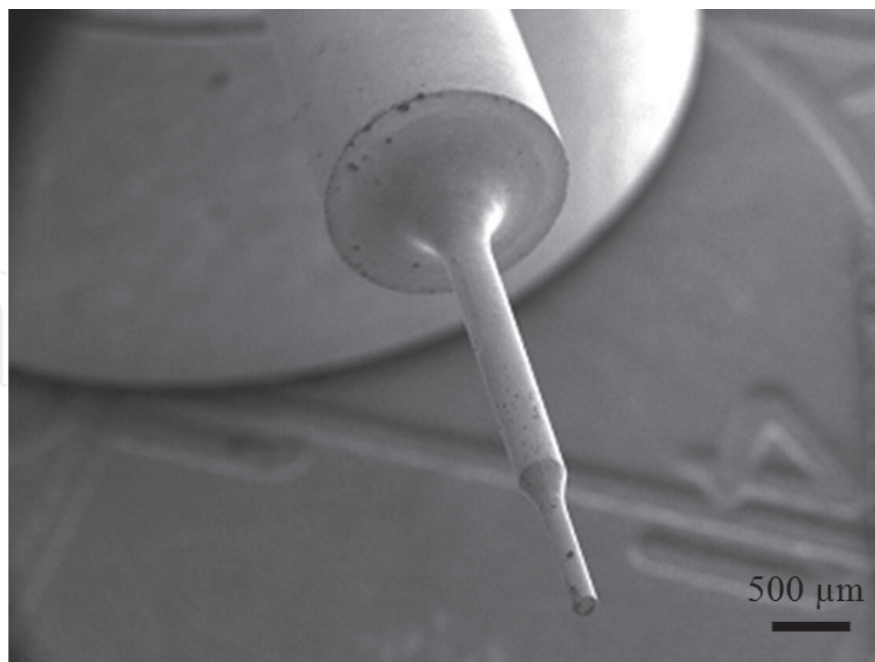
However, tool wear is an important issue in micro punching. Even with punches made of hard and tough materials like tungsten carbide-cobalt (WC/Co), quality of the punched holes declines rapidly under repeated punching [7].

Therefore, the effect of cobalt on the morphology of microhole formed by punching pure titanium (Ti) with WC/Co micropunches was investigated. The morphology variation of the micropunched holes at various cobalt volumes was measured by scanning electron microscopy (SEM), energy dispersive spectrometer (EDS) and confocal laser to reveal the relationship between the morphology of punched microhole and the ratio of cobalt in the micropunch.

## 2. Experimental materials and procedures

### 2.1. Experimental material

Micropunches with 75, 50, 25% volume fraction of WC particle and 25, 50, 75% volume fraction of Co particle of 50  $\mu\text{m}$  mean size, 150  $\mu\text{m}$  in diameter, was fabricated, respectively. The typical profile of the fabricated micropunch is shown in **Figure 1**. Pure titanium sheet with 200  $\mu\text{m}$  in thickness was used as the substrate.



**Figure 1.** Profile of micropunch.

## 2.2. Experimental procedures

The prepared pure titanium sheet was properly cleaned by acetone and pure ethyl alcohol so as to remove any possible contaminant and carefully put into the microdie. Thereafter, specimens were punched by the microprocessing machine MP50 (made in Japan) with 20 pulses per minute and feedrate of 2 mm.

Punching experiments were done using an in-house setup. Precise vertical alignment during punching is crucial as lateral position error can lead to premature tool wear, tool breakage as well as inferior quality of the punched holes. The setup contained a vertical motion carriage with less than 1.5  $\mu\text{m}$  lateral error over the 20 mm vertical stroke. The punch gripper that hosted the micropunch was fixed to the carriage. The stroke and load (maximum 20 N) of the carriage were provided by a z-stepper through a push rod. Specimens were held between a pair of 5 mm diameter bushes during the micropunching. The bush material was WC/Co, same as that of the micropunch. The bushes contained a 200  $\mu\text{m}$  through-hole with 10° taper. The upper and lower faces of the bushes were carefully ground to ensure flatness and parallelism.

The effect of cobalt on the morphology of microhole at various micropunches was investigated by scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS). The diameter of the machined microhole by micropunch was measured by LEXT confocal laser-OLS3000.

## 3. Results and discussion

### 3.1. Wear of micropunches with various cobalt ratios

In the micropunching, the wear of three types of micropunches in the initial is all significantly increased [7], and the dominant factor of the wear loss is mainly due to Co.

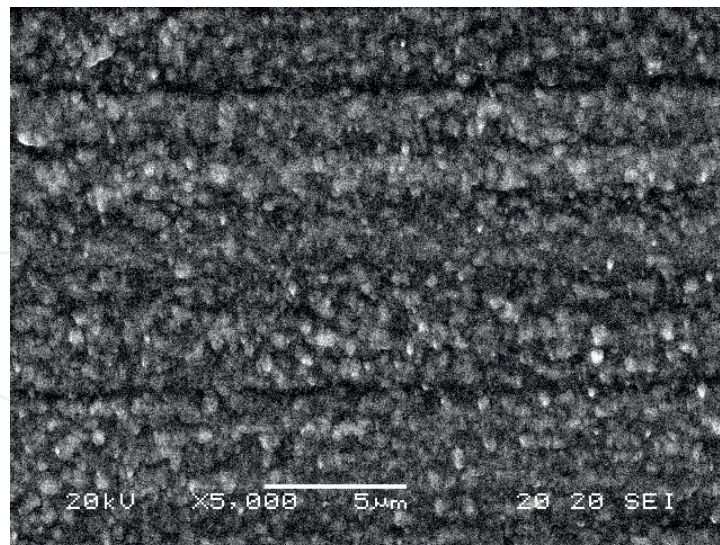
With the punching number increasing, the wear of WC/Co micropunch is in the quasistable period with a little wear loss.

**Figure 2** illustrates its corresponding surface textures of three types of micropunches. It shows small pieces of WC particles distribute uniformly on the surface with 75% WC + 25% Co as shown in **Figure 2a**. While the volume fraction of Co increases, WC particles cannot observe distinctively, especially for the result shown in **Figure 2c**. It indicates that the fabricated micropunches with higher volume fraction of Co particles are not suitable for micropunching to meet with the desired requirements.

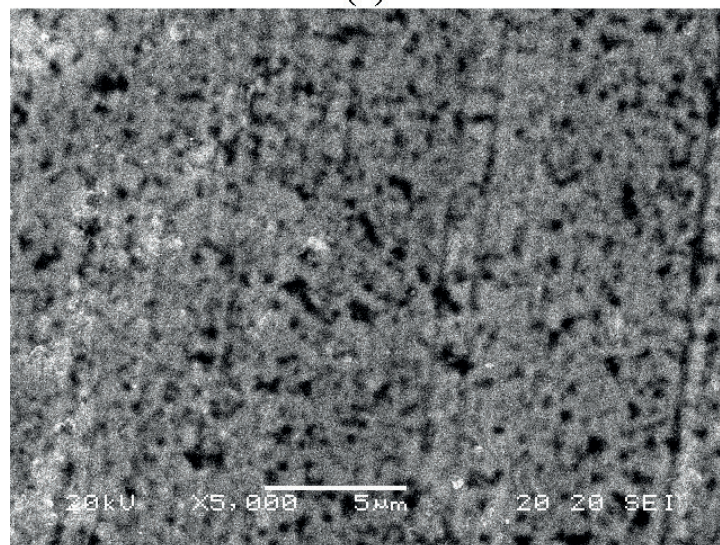
### 3.2. Effect of cobalt on morphology of punched microholes

The morphology of the punched microholes in the quasistable condition is shown in **Figure 3**. It illustrates that although there distributes some debris in the back side (**Figure 3a(ii)**, **b(ii)** and **c(ii)**), the profile of microhole formed with 75% WC + 25% Co is obviously better than that of the other two types (cf. **Figure 3a–c**).

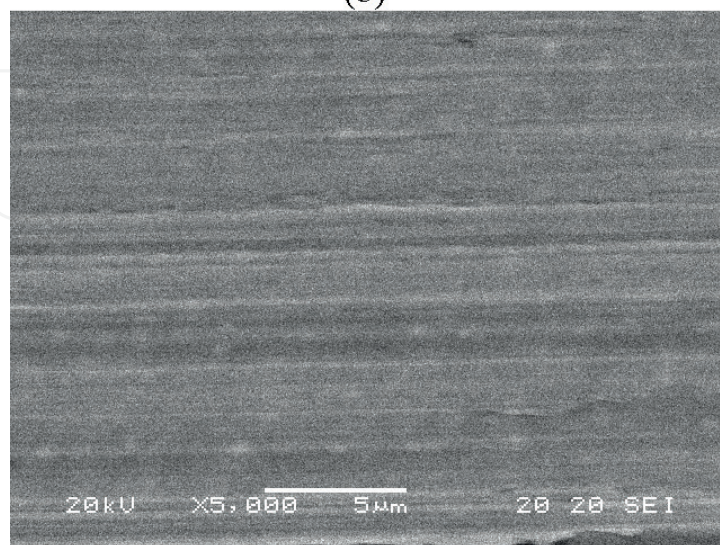




(a)



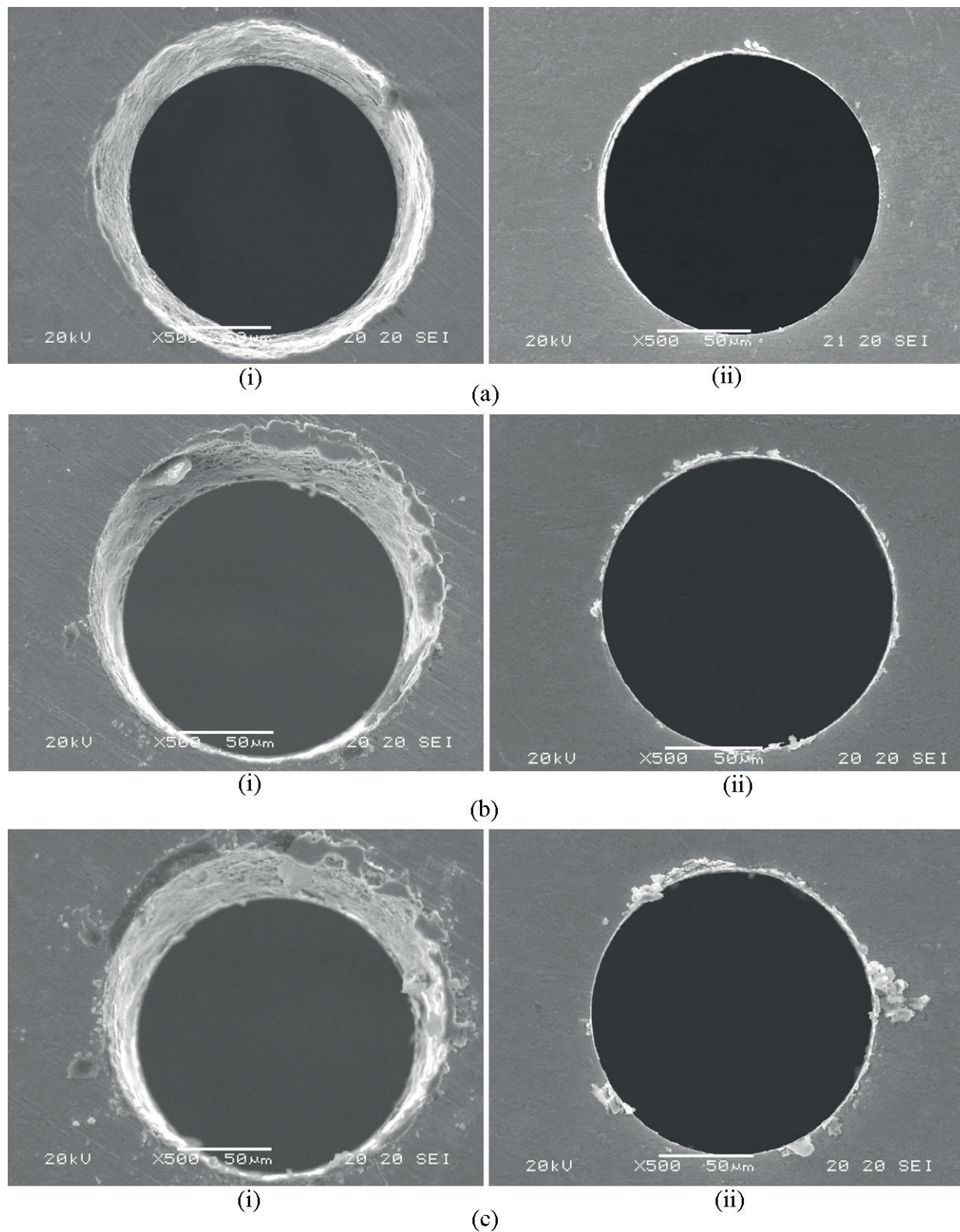
(b)



(c)

**Figure 2.** Surface texture of micropunches in the quasistable condition. (a) 75% WC + 25% Co. (b) 50% WC + 50% Co. (c) 25% WC + 75% Co.





**Figure 3.** Morphology of punched microholes. (a) 75% WC + 25% Co. (b) 50% WC + 50% Co. (c) 25% WC + 75% Co.

Moreover, with the increment of Co, the debris distributed both on front and back sides increases. The morphology of the punched microhole is not even well, especially for the front side (**Figure 3b(i)** and **c(i)**). For the punches with 50% WC + 50% Co and 25% WC + 75% Co,

the large bulk debris distributed on the surface results in the lower quality of the microhole, especially for the microholes punched with 25% WC + 75% Co.

It reveals that due to the optimal joint-contribution of WC and Co, i.e. 75% WC + 25% Co, the morphologies of the punched microholes not only satisfy with the practical requirements but also the wear loss of micropunch in the quasistable period is at the lowest level.

Furthermore, only small variation of the diameter of the microhole was experienced in the quasistable stage by the micropunch with 75% WC + 25% Co, as the weight loss was also small in the quasistable condition [7].

### 3.3. Effect of cobalt on life of micropunches

The life of types of micropunches is shown in **Figure 4**. It elucidates that the life of micropunch with 75% WC + 25% Co is definitely longer than the other two types, which agrees with the results shown in **Figure 2**. The effective punching number of the micropunch with 75% WC + 25% Co is about 1200. On the contrary, the life of micropunches with 50% WC + 50% Co is lower than 600. Even worse, for punches with 25% WC + 75% Co, its effective punching number is less than 100. Consequently, as an achievable tool for fabricating microholes, the micropunches with 50% WC + 50% Co and 25% WC + 75% Co are not capable for micropunching.

### 3.4. Quasistable wear characteristic of micropunch with 75% WC + 25% Co

The relationship between the wear loss 75WC/25Co micropunch and punching numbers is shown in **Figure 5**. It shows that the weight of 75WC/25Co micropunch (each for five times) has an obvious decrease with the increment of punching number in the initial.

After the obvious wear of 75WC/25Co micropunch in the initial and with the punching number increasing, the wear of 75WC/25Co micropunch is in the quasistable period with a little wear loss as shown in **Figure 5**, especially for punching number from 500 to 1200. **Figure 6** illustrates its corresponding surface texture of 75WC/25Co micropunch. It shows that small pieces of WC particles are observed on the surface. In the meantime, WC particles are distributed uniformly on the micropunch surface.

As comparison, the morphology of the punched microhole by 75WC/25Co micropunch in the initial period is expressed in **Figure 7**. Some substrate debris is distributed sparsely in the back side as shown in **Figure 7b**, and its EDS results are illustrated in **Figure 8**.

According to the morphology of the microhole punched by 75WC/25Co micropunch as shown in **Figure 3a**, it illustrates that although there still distributes some substrate debris in the back side, the profile of microhole formed in quasistable period is better than that of the initial period (cf. **Figures 3a** and **7**). It reveals that due to the joint-contribution of WC and Co with the optimal ratio (75% volume fraction WC particle + 25% volume fraction Co), the wear loss of micropunch in the quasistable period is the least among the three types of micropunches.

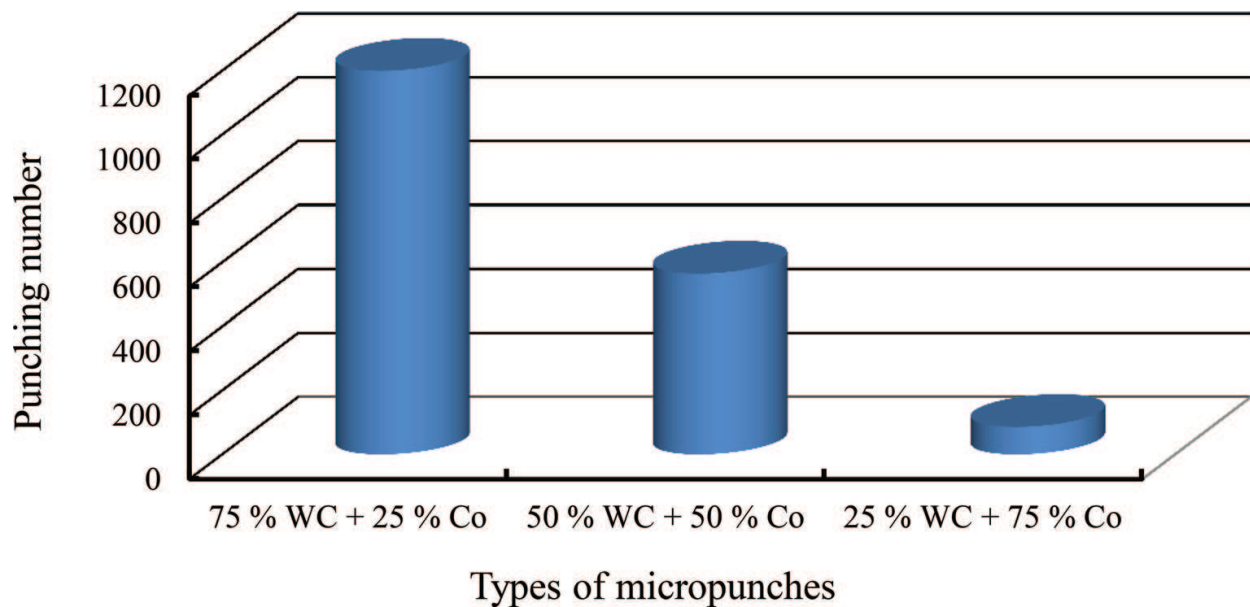


Figure 4. Life of different micropunches.

### 3.5. Profile of the microhole punched by 75WC/25Co micropunch

The diameter of the punched microhole by 75WC/25Co micropunch was measured by LEXT confocal laser-OLS3000 as shown in **Figure 9**. Its corresponding results (each for five times) are shown in **Figure 10**.

Compared with **Figure 5**, it illustrates that in the different wear conditions the diameter of microhole is changed correspondingly. In the initial condition, the diameter of microhole decreases obviously with the increment of punching number, which definitely agrees with results shown in **Figure 5**. While the punching number is from 500 to 1200, the diameter of microhole is relatively kept stable. With the punching number increasing further, especially when the punching number

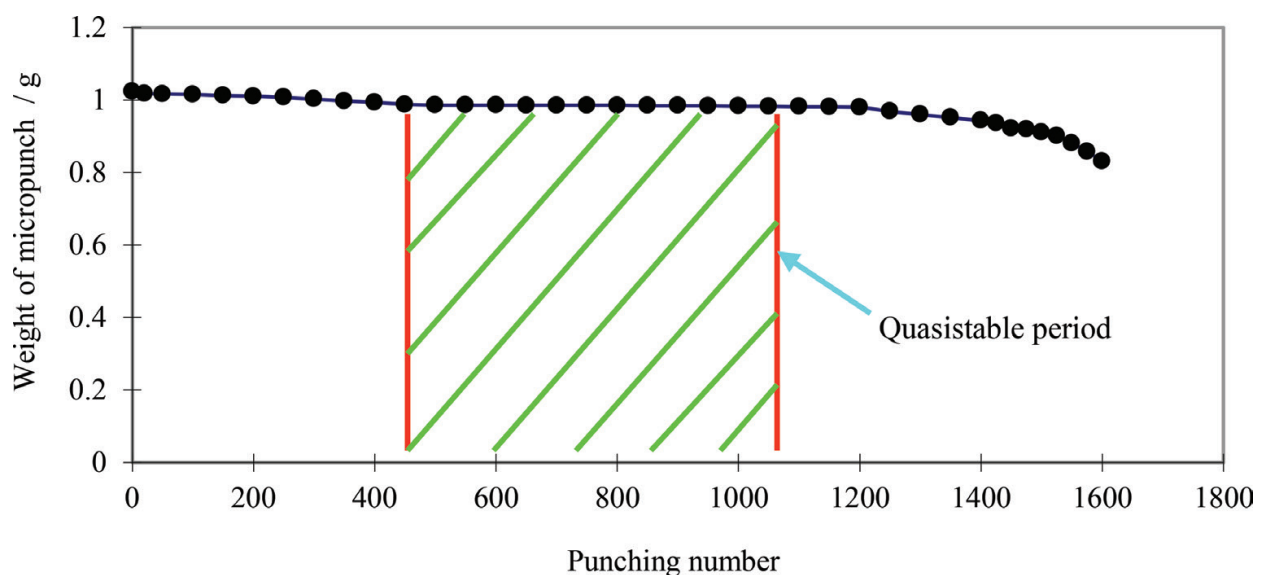
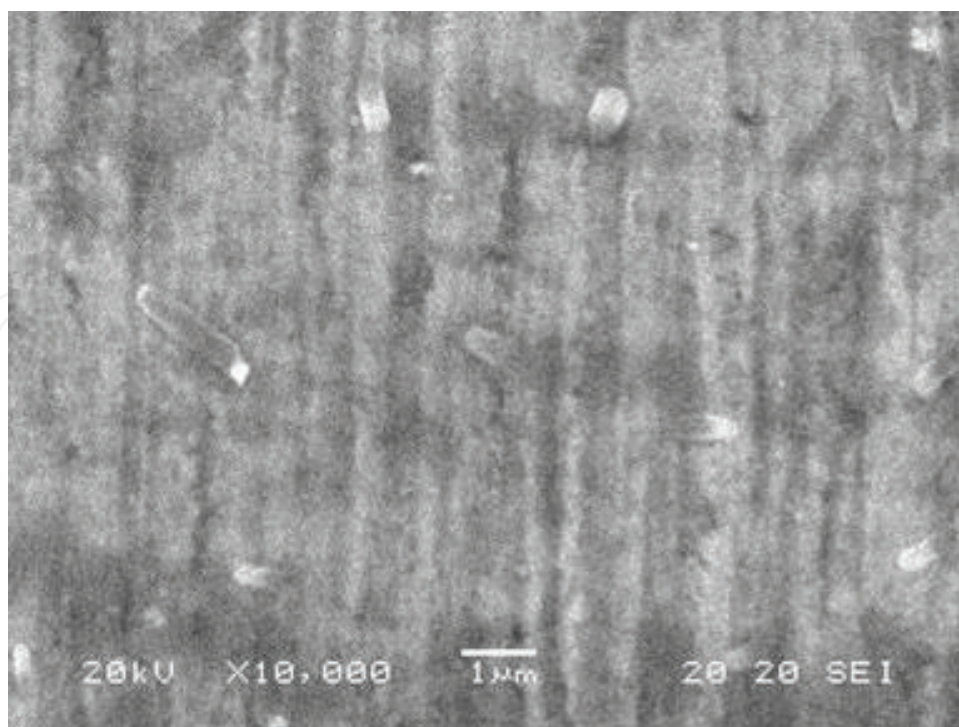


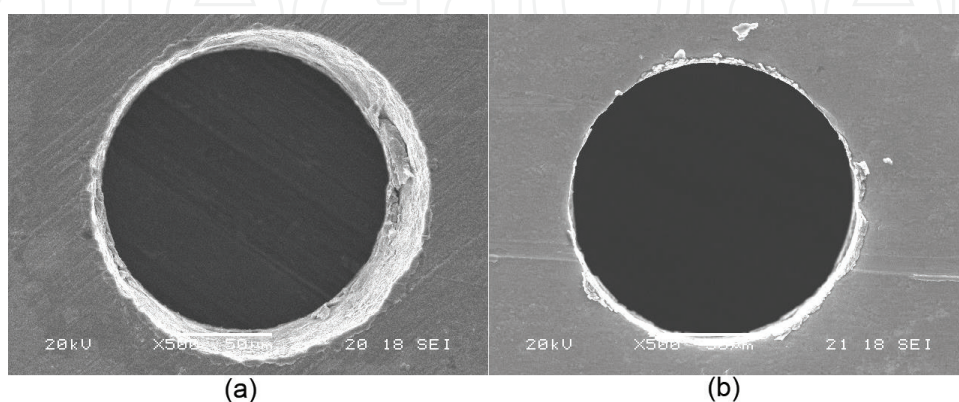
Figure 5. Relationship between wear loss of 75WC/25Co micropunch and punching numbers.





**Figure 6.** Surface texture of 75WC/25Co micropunch in the quasistable condition (punching number between 500 and 1200).

exceeds 1525 as shown in **Figure 10**, the diameter of microhole decreases remarkably because of the serious loss of Co. Consequently, the serious wear of micropunch mainly relies on WC particles which are easily peeled off without Co as bonding material in the severe wear condition of micropunching. Meanwhile, due to the temperature increment with punching number increasing, WC particles are more easily peeled off resulting in more intensive wear loss. Moreover, if the punch number increases in a minute, the wear loss of micropunch will be more drastically. In addition to the abovementioned, the microstructure of micropunch should be considered further, especially for the distribution of WC and Co particles.



**Figure 7.** Morphology of microhole punched by 75WC/25Co micropunch in the initial period. (a) Front side. (b) Back side.

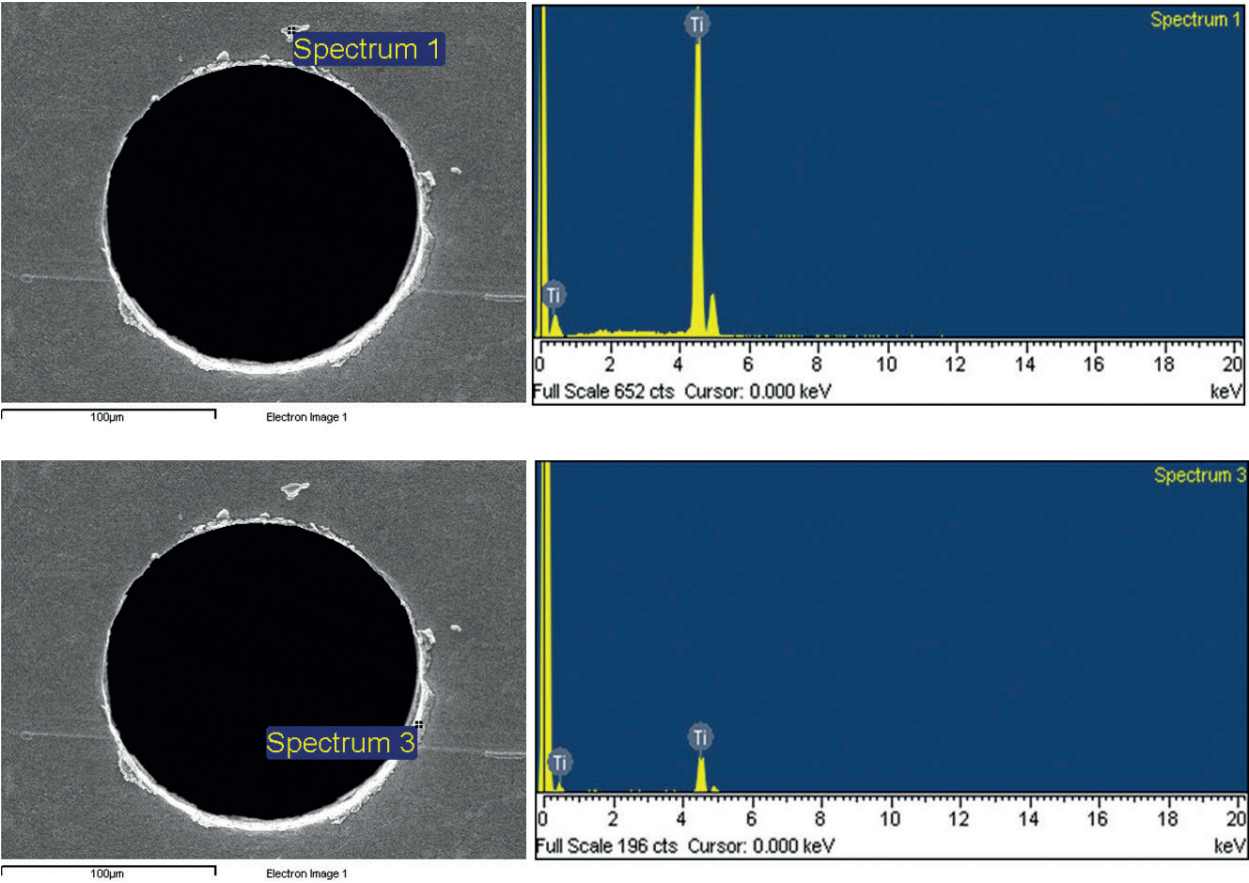


Figure 8. EDS results of debris in the back side.

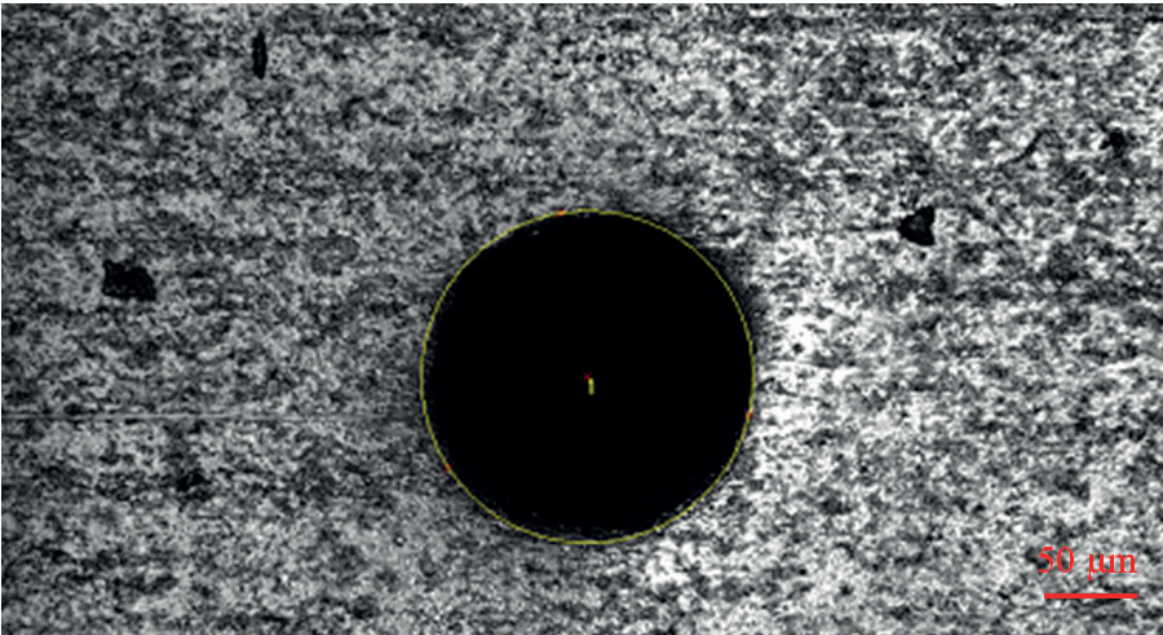
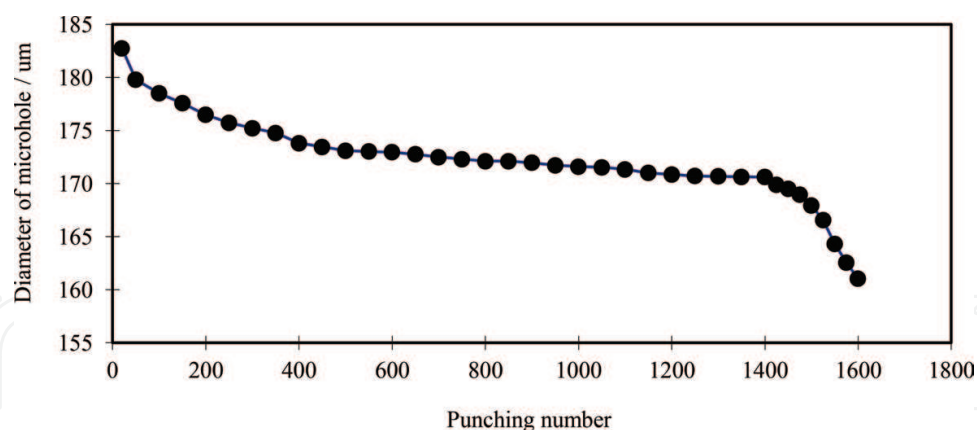


Figure 9. Profile of microhole punched by 75WC/25Co micropunch measured by OLS3000.





**Figure 10.** Relationship between diameter of microhole and punching number.

## 4. Conclusion

The effect of cobalt on the morphology of microhole formed by punching had been researched with three types of WC/Co micropunches. It shows that the quality of micropunch with 75% vol. WC + 25% vol. Co is distinctively better than the other two types. Meanwhile, it reveals that due to the optimal joint-contribution of WC and Co, the morphologies of the microholes punched by 75WC/25Co micropunches not only satisfy with the practical requirements but also the relevant punch using life is at the highest level among the three types of micropunches. As for 75WC/25Co micropunch, when the punching number exceeds 1525, the serious wear of micropunch occurs with the wear loss of Co and WC. Moreover, with the punching numbers further increment, the dominant factors of the wear loss would mainly rely on the easily peeled off WC due to the serious loss of Co.

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## Author details

Kelvii Wei Guo\* and Hon Yuen Tam

\*Address all correspondence to: kelviigu@yaho.com

Department of Mechanical and Biomedical Engineering, City University of Hong Kong, Hong Kong



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