Improved Hole Wall Roughness and Corrosion Resistance of U-Shaped Hole Prepared by Casting

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Research Article

Keywords: Cooling water channel, Water-cooled mold, U-shaped hole, Roughness, Corrosion resistance

Posted Date: February 26th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-242952/v1

Version of Record: A version of this preprint was published at The International Journal of Advanced Manufacturing Technology on August 9th, 2021. See the published version at https://doi.org/10.1007/s00170-021-07771-3.

Abstract

The corrosion resistance of the cooling water channel in the water-cooled mold has an important impact on the application of the mold. In this paper, the influence of experimental temperature on roughness and corrosion resistance of U-shaped cooling channels prepared by casting is analyzed in detail. The results show that the experimental temperature increased from 998K to 1048K, the hole wall roughness of the U-shaped hole decreased from 83.264 to 76.287. However, the hole wall roughness increased with a further increase in temperature. Because the low experimental temperature will promote the formation of micro bulges and river ripples on the hole wall. However, with the temperature gradually increased, it will promote the aluminum matrix to react with the carbon fiber, which will increase the roughness. The corrosion performance analysis results show that a reasonable experimental temperature is beneficial to reduce the roughness of the hole wall and improve the corrosion resistance of the cooling channel. When the roughness is large, the ravines on the rough surface are easy to be the starting point of corrosion. At the same time, it is easy to cause the aggregation of Si elements to the hole wall at high experimental temperature, which will also cause corrosion. As a result, reasonable experimental temperature plays an important role in improving the corrosion resistance of the U-shaped cooling channel.

1. Introduction

Stamping forming is currently the most convenient and effective technology in industrial product forming, and the mold is the core of this technology[1,2]. In the process of hot stamping, the design of the cooling water channel in the mold has a very important influence on the forming of parts[3-7]. By optimizing the cooling water channel of the mold, not only the cooling period of the parts can be shortened, but also the defects of the product can be reduced, and the accuracy and the mechanical performance of the product can be improved[8-10].

Sachs et al[11,12] first proposed follow-type cooling technology and used 3D printing to prepare injection molds with follow-type cooling channels. The research shows that the mold can ensure the same distance between the cooling water channel and the mold cavity compared with the traditional cooling water channel, which can not only improve the cooling efficiency, but also improve the product quality significantly. At present, with the continuous development of 3D printing technology, metal 3D printing technology can realize the preparation of metal molds with any shape cooling water channels. However, the long molding cycle and high price of 3D printing technology limit its industrial application. Park[13,14] proposed follow-type cooling channels with array of baffles for plastic injection mold. Although this method is simpler and cheaper than 3D printing, the water-cooling mold prepared by this method is easy to cause leakage problems. Dang et al[15]reported that the U-shaped cooling channel was obtained by using traditional drilling and inlaying methods. Although the process scheme is simple in the process of hole processing, the insufficient precision of each part during the inlay process is easy to cause leakage. Although many scholars have used numerical simulation calculations to show that the mold of conformal cooling is good, they have not proposed a better way for the preparation of the mold.

Qu et al[16-18]first proposed to prepare U-shaped holes by casting process, because of the characteristics of poor wettability and low thermal expansion coefficient between carbon fiber and aluminum melt. Using the casting process to prepare the mold with follow-type cooling channel is simple and efficient compared to other processes, which will provide an important theoretical and applied basis for the preparation of the water-cooling mold. However, the surface roughness of the cooling water channels prepared by the casting method is larger than that prepared by the drilling method and 3 D printing method, which may lead to the risk of corrosion and leakage in practical application. In this paper, the influence of experimental temperature on the roughness and corrosion resistance of the U-shaped cooling channels prepared by casting was analyzed in detail.

2. Experimental Materials And Methods

2.1. Experimental material

The experimental matrix material was Al-12Si alloy, stainless steel wire (with a diameter of 1.5mm) winding around carbon fibers was used as hole core, and the porous ceramic is used to fix the core. The carbon fibers were produced by the Institute of Coal Chemistry at the Chinese Academy of Sciences with a diameter of 7-8 μm.

2.2. Methods

The process was shown as follows, the carbon fiber bundle was wound evenly on the U-shaped metal wire to make U-shaped hole core with a diameter of 2 mm. The two ends of the U-shaped hole core were fixed through the ceramic grids, then the prefabricated body was placed in the metal cavity, and preheated at a temperature of 623K, as shown in Fig. 1. The Al-12Si alloy was heated to a liquid state and poured into the metal mold at 1073K, 1048K, 1023K, and 998K temperature, respectively. After cooling to room temperature, the whole hole core was extracted from the matrix alloy to prepare U-shaped hole.

2.3 Microstructures and properties

The macrostructure of the hole wall was photographed using a Nikon D7500 Digital Single Lens Reflex. OLS3400 3D measuring laser microscope was used to investigate the effects of experimental temperature on the morphology of the curved hole. The microstructure of the specimens was characterized by scanning electron microscopy (SEM) using a Phenom G6 pure and the chemical composition distribution was investigated by energy dispersive spectrometry (EDS).

3. Results And Discussion

3.1 Effect of temperature on U-shaped hole morphology

Fig. 2 shows a U-shaped hole was fabricated by casting with carbon fiber as the core material. It can be seen that a complete through curved hole is achieved and the diameter is very uniform. The overall length of the U-shaped hole is 200 mm, the hole diameter is 2mm and the aspect ratio can reach to 100.

The hole wall morphologies of the U-shaped hole prepared at different temperatures are shown in Fig. 3. It can be seen that the inner wall is very flat, there is no obvious pit defect, and the hole diameter is very uniform.

Fig. 3(a) shows the wall morphology of the U-shaped hole prepared at the temperature of 998K. The roughness test showed that the roughness of the hole wall is 83.264. With the increase of temperature, the roughness of hole wall morphology decreases gradually, and the roughness of the U-shaped hole prepared at 1023K and 1048K are 79.857 and 76.287, respectively, as shown in Fig. 3(b)-(c). King et al[19] reported that the wettability between molten metal and hole core has an important effect on the morphology of hole wall. The decrease in wettability would promote the formation of micro bulges and river ripples on the hole walls, which would increase the roughness of the hole wall. With the increase of temperature, the wettability between carbon fiber and aluminum melt increase gradually, so the roughness of the inner wall of the hole decreased gradually. However, when the experimental temperature was raised to 1073K, the roughness of the inner wall of the hole increased slightly to 89.681. This is because when the melt temperature reaches to 1073K, the carbon fibers will react obviously with the aluminum melt. Pradeep et al[20] reported that the Gibbs Free Energy of the reaction between carbon fiber and the aluminum substrate can reach -163297.4 kJ/mol at 1073K, which is a large negative number for good roughness. As shown in Fig. 4, it can be seen that there are obvious carbon elements at hole wall when the U-shaped hole prepared at 1073K, which indicates that the carbon fiber hole core reacted with the molten metal aluminum, so the roughness of the hole wall is slightly higher.

3.2 Effect of temperature on the behavior of exfoliation corrosion

Exfoliation corrosion is a common type of local corrosion, which has serious harm to the application of aluminum alloy. The exfoliation corrosion is easy to cause the leakage problem for the follow-type cooling channel. Therefore, it is necessary to study the exfoliation corrosion behavior of the U-shaped holes prepared by the casting method. Fig. 5 shows the surface morphologies of the hole wall of the U-shaped hole prepared at 1048K after corrosion treatment at different times.

It can be seen that with the increase of corrosion time, the surface of the hole wall changes obviously. After 12 h, as shown in Fig. 5(a), the surface of the specimen lost luster and appeared slight pitting phenomenon. With the increase of the corrosion time, the pitting corrosion began to increase and the number began to increase. After 48 h, a large number of pitting corrosion and serious discoloration appeared on the surface of the specimen, as shown in Fig. 5(d). With the corrosion time increases, the roughness also changes significantly. The roughness increased from 76.287 to 82.588 after 48 h of corrosion.

Fig. 6 shows the surface morphologies of the specimens prepared at different temperatures after 48 h corrosion treatment. It can be found that the roughness first decreases and then increases with the increase of the preparation temperature. This is due to the large roughness of the hole sample prepared at 998K, the ravines on the rough surface are easy to be the starting point of corrosion during exfoliation corrosion, which will lead to a further increase in hole wall roughness.

With the experimental temperature increase to 1073K, the removal of carbides formed by the reaction between the carbon fibers and the matrix at high temperature from the surface of hole wall during corrosion is an important reason for the increase of roughness. In addition, the microstructure of the sample prepared under the condition 1073K was observed after 48 h exfoliation corrosion, as shown in Fig. 7. It can be seen that there is a phenomenon that silicon will be corroded and peeled from the surface of the U-shaped hole. During the preparation process, the long stay of aluminum melt at high temperature will not only cause the reaction between carbon fibers and aluminum matrix, but also cause the segregation of silicon elements. Under liquid conditions, the values of the mixing enthalpy between carbon and silicon is -39kJ/mol, and between carbon and aluminum is -39kJ/mol, which are much lower than the mixing enthalpy value of -19 kJ/mol between aluminium and silicon. The lower value of the mixing enthalpy between elements in the liquid metal, the easier cause element bonding. Therefore, a high experimental temperature will cause silicon to aggregate on the wall of the hole, which is consistent with the results of Zhang et al[21]. Therefore, the reaction between the carbon fiber and the matrix and the segregation of silicon on the surface of the hole wall reduce the exfoliation corrosion resistance of the U-shaped hole prepared at 1073K.

3.3 Effect of temperature on intergranular corrosion behavior

Fig. 8 shows the microstructure at the cross-section of U-shaped hole samples prepared under different temperatures after 6 h intergranular corrosion. It can be seen that the depth of intergranular corrosion increases with the increase of preparation temperature. The corrosion depth of U-shaped hole prepared at 1023K is only 156μm, as shown in Fig. 8(b). However, when temperature increases to 1073K, the corrosion depth reaches 220μm, as shown in Fig. 8(d). It can be seen that the corrosion goes deep into the matrix along with the eutectic silicon. Because the segregation of silicon elements on the surface of the hole wall at 1073K, it will lead to significant potential difference between the precipitated phase and the aluminum matrix, and promote the intergranular corrosion of aluminum alloy. This is consistent with the research results of Svenningsen et al on the driving force of intergranular corrosion of aluminum alloy[22]. Therefore, reasonable experimental temperature plays an important role for obtaining a follow-type cooling channel with good corrosion resistance.

4. Conclusion

In this paper, the U-shaped cooling water channel was successfully fabricated by casting method. The study of the U-shaped cooling water channel will provide an important theoretical basis for the application of follow-type cooling channel mold in the future. The specific experimental conclusions of this study are as follows:

1. In the process of preparing U-shaped holes by the casting method, a low temperature easily causes the formation of micro bulges and river ripples on the hole wall, and a high temperature will cause a reaction between the carbon fibers, which will cause the roughness of the hole wall to increase.
2. The ideal experimental temperature during the preparation of the U-shaped cooling channel is 1048K. At this time, the hole wall has a relatively low roughness of only 76.287, as well as has a relatively excellent corrosion resistance.
3. The high experimental temperature will also cause the segregation of silicon on the hole wall because of the low mixing enthalpy between Si element and carbon fiber, which will seriously reduce the corrosion resistance of the cooling water channel. The obvious potential difference between silicon and aluminum matrix will also promote the intergranular corrosion of aluminum alloy.

Declarations

Acknowledgment

This research was supported by the National Nature Science Foundation of China (No. 51775353) and Special Professor Project in Liaoning Province (No. 2018-35-21).

Author Contributions

Yingdong Qu designed the experiments, Yang Cao and Guanglong Li conducted the experiments, Rongde Li and Ruirun Chen guided experiments, Sainan Nie and Chang Tian carried out experimental tests, Yang Cao and Guanglong Li analyzed the data and wrote the paper. All authors discussed the results and reviewed the manuscript.

Competing financial interests: The authors declare no competing interests.

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Figures

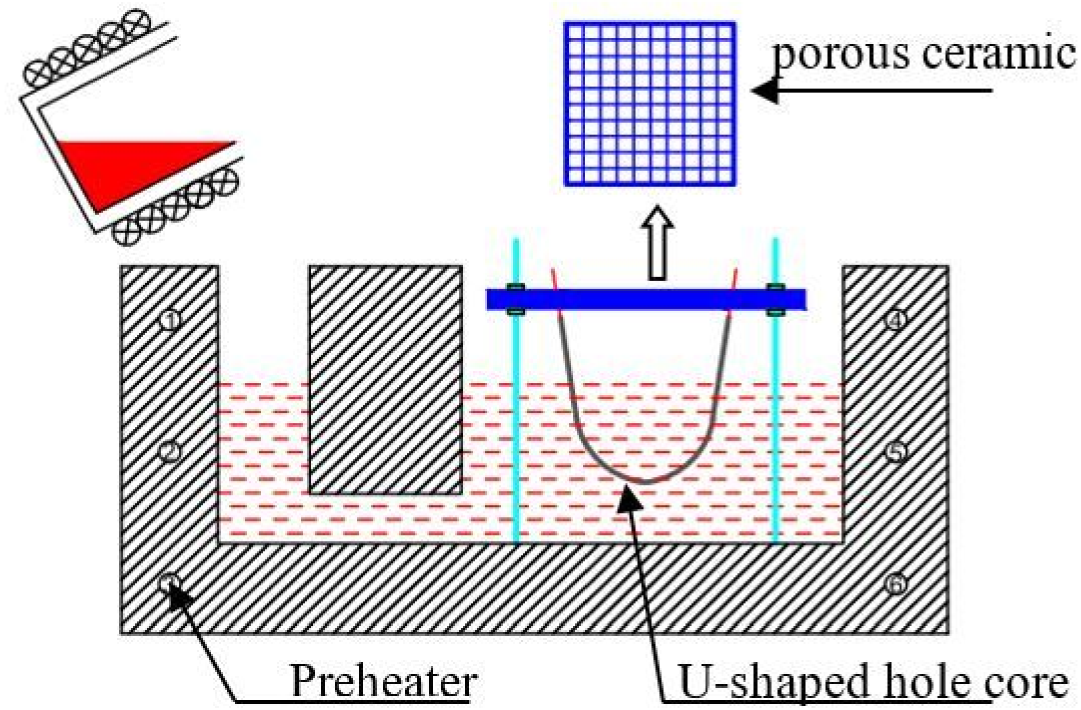

Figure 1

Manufacturing processes

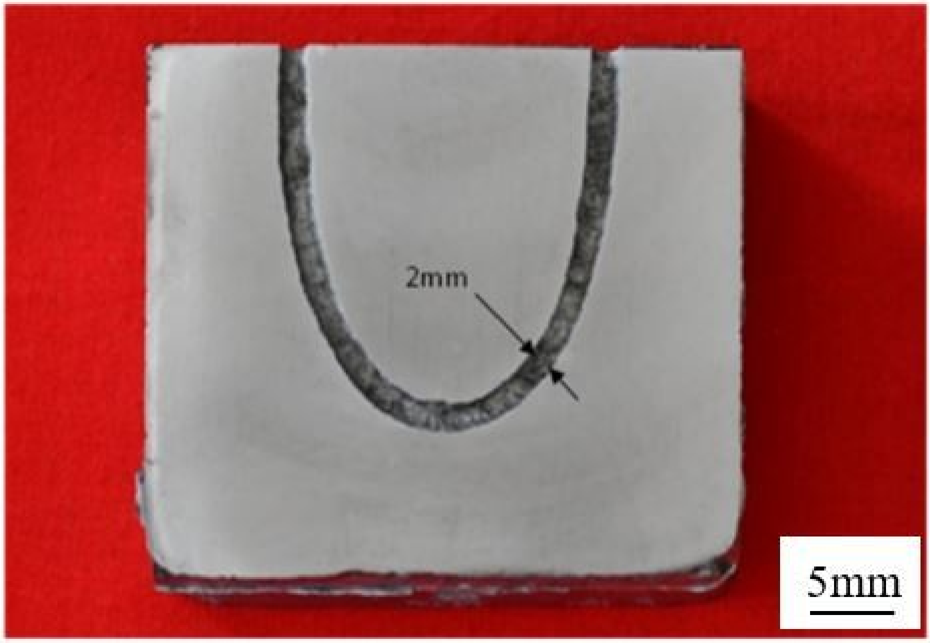

Figure 2

Cross-section of the U-shaped hole

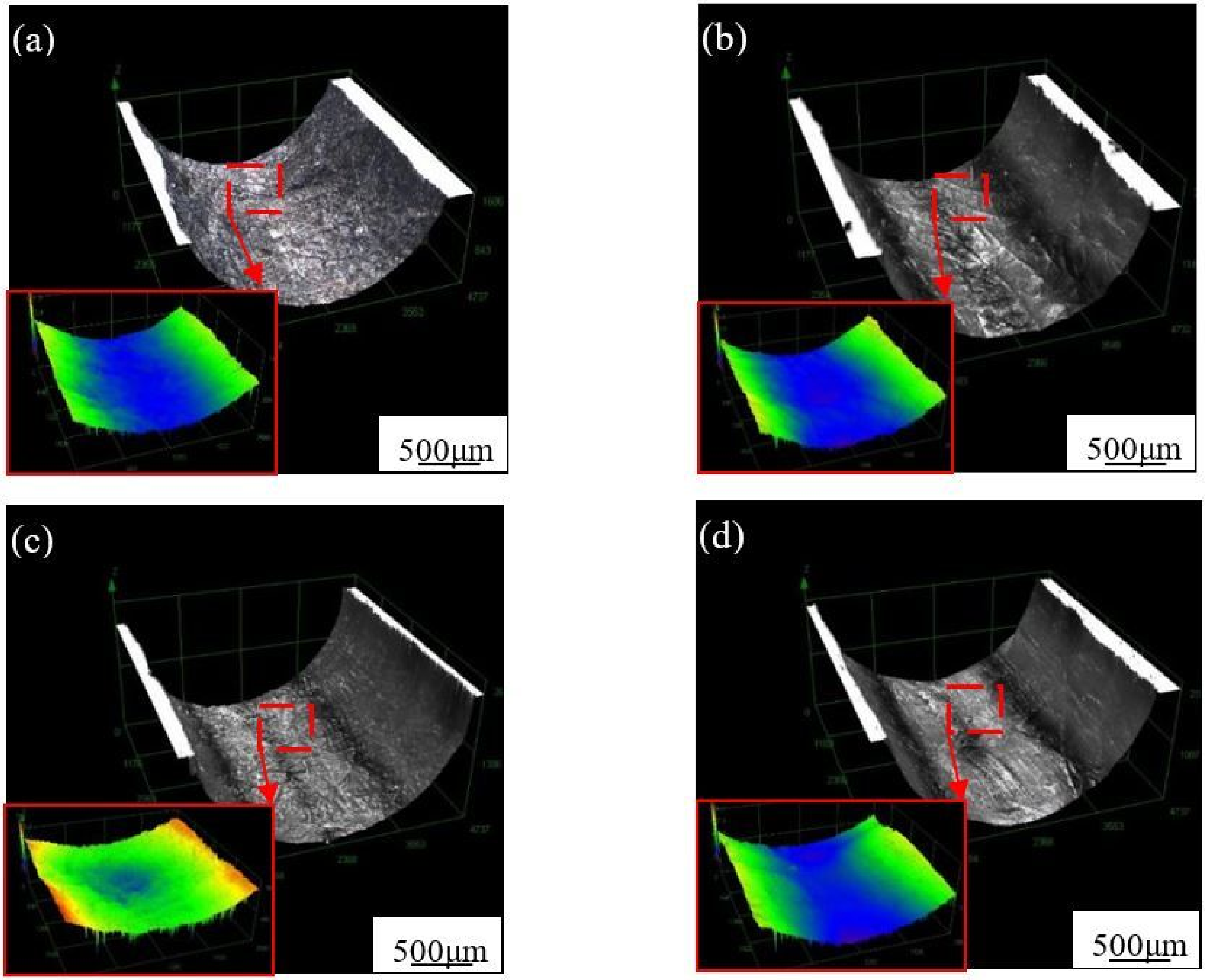

Figure 3

Hole wall morphologies of U-shaped holes prepared at (a) 998K, (b) 1023K, (c) 1048K, (d) 1073K

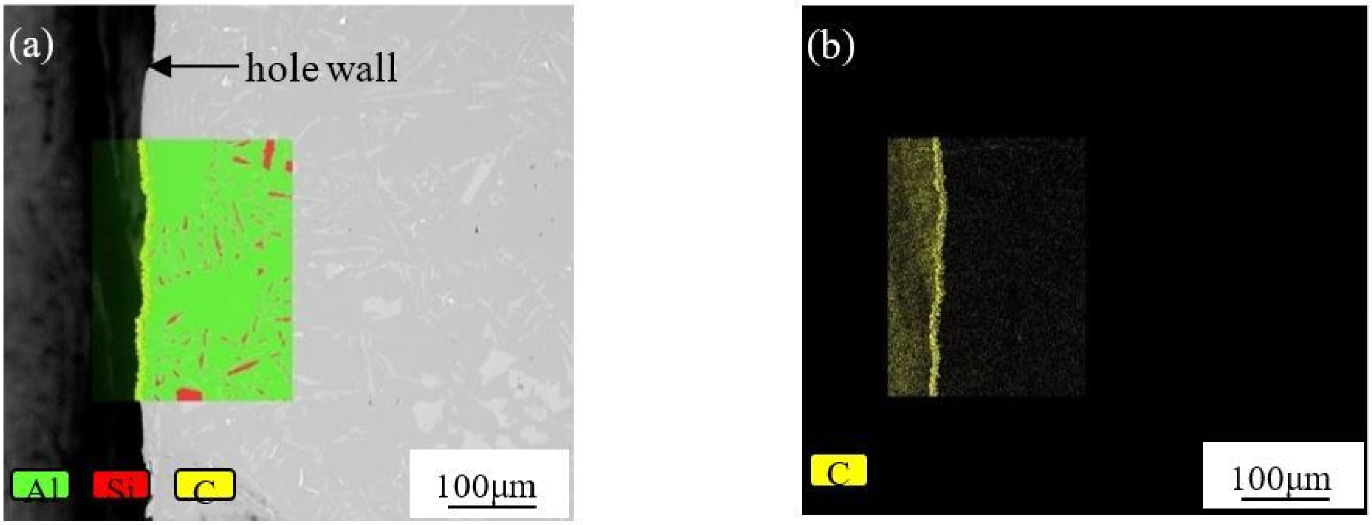

Figure 4

Energy spectrum of U-shaped hole (a) morphology (b) carbon element distribution

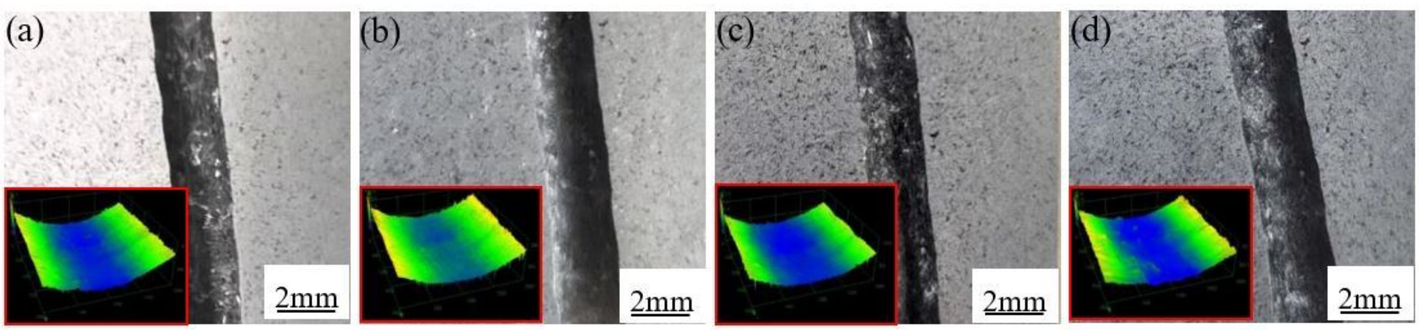

Figure 5

Surface morphologies of U-shaped hole prepared at 1048K after exfoliation corrosion of (a) 12h, (b) 24h, (c) 36h, (d) 48h

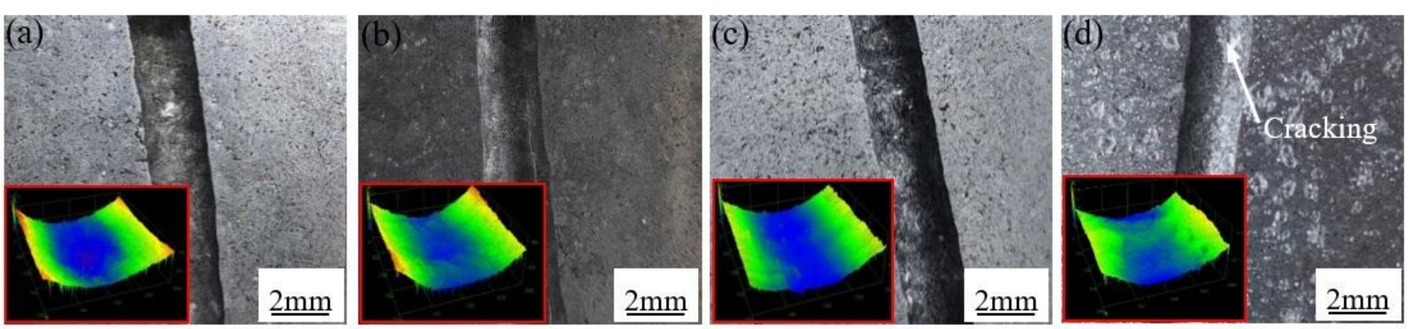

Figure 6

Surface morphologies of U-shaped holes prepared at different temperature after 48h exfoliation corrosion (a) 998K, (b) 1023K, (c) 1048K, (d) 1073K

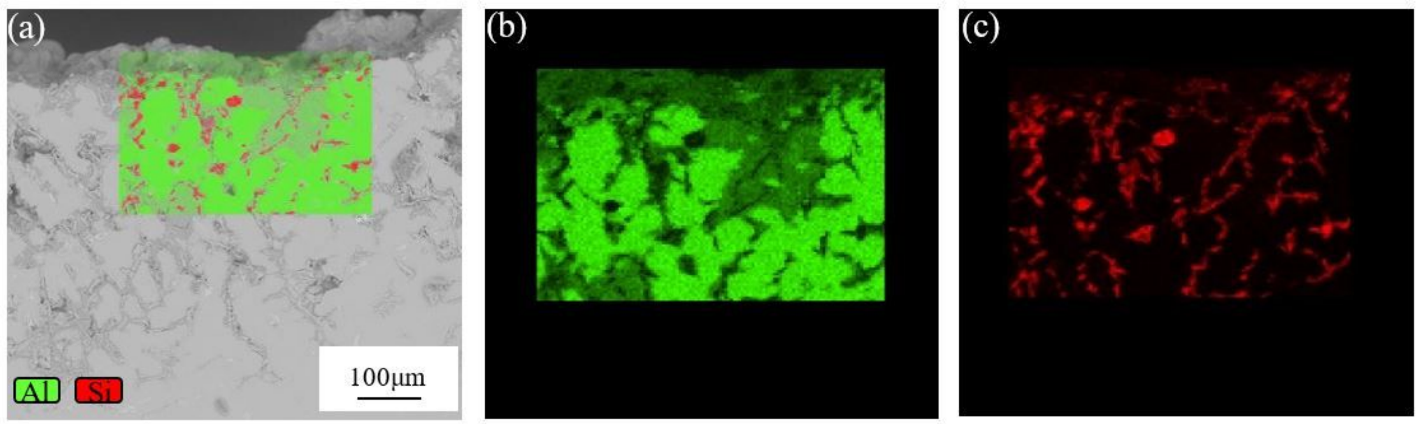

Figure 7

Internal morphology of U-shaped hole prepared at 1073K after 48h of exfoliation corrosion (a) morphology (b) aluminum element distribution (c) silicon element distribution

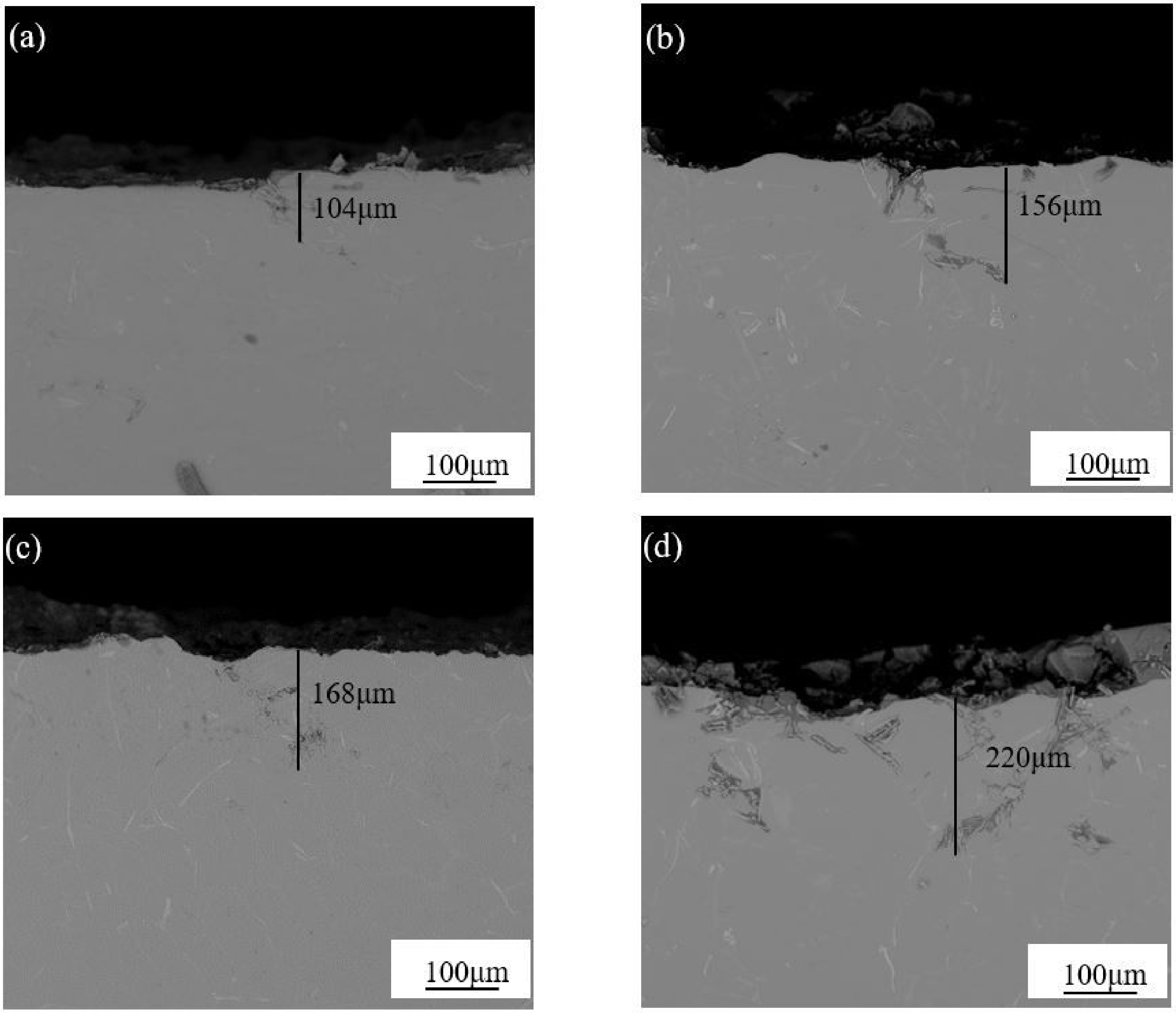

Figure 8

Internal morphologies of U-shaped hole prepared at different temperature after 6h of intergranular corrosion (a) 998K, (b) 1023K, (c) 1048K, (d) 1073K