

# RESEARCH ON THE GRINDING PERFORMANCE OF HIGH PRESSURE SINTERING SiC<sub>p</sub>/Al MATRIX COMPOSITES

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## Abstract:

The two-dimensional vertical grinding test equipment was used to grind SiC<sub>p</sub>/Al composites which were prepared by high pressure sintering method. The SEM observation of grinding morphology showed that grinding damage can be prevented by SiC particles reinforcement, 60% volume fraction of SiC particles of SiC<sub>p</sub>/Al composite can hinder grinding depth and grinding performance was improved with the sintering pressure and temperature increasing. In addition, some scratches and exfoliated pits of SiC particles were observed on the surface of 60% volume SiC<sub>p</sub>/Al composite as the increase of grinding grain, while the depth of these scratches was shallower, there was no large area exfoliated pits of SiC reinforcements.

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## 1 Introduction

With the development of science and technology, especially in the fields of aerospace, transportation, ocean engineering and precision instruments, the requirement for high performance materials is becoming more and more urgent. On the one hand, materials are required to achieve high specific strength, high stiffness, fatigue resistance, etc. On the other hand, the materials need to adapt to the working environment of high temperature and pressure, fine vacuum, and deep etching [1-4]. Most of the traditional materials cannot meet the requirements mentioned above, promoting the development of composite materials [5]. The aluminum matrix composites strengthened by SiC particles have some good performances, such as low density, high specific strength, and specific stiffness, high thermal conductivity, small linear expansibility, low dilatation, good dimensional stability and wear resistance, corrosion resistance, ray resistance etc. [6-9]. Besides, the raw materials

of SiC reinforced aluminum matrix composites can be obtained easily, so the manufacturing cost is low and the material can be adapted to market easily. It is a new structure material possessing great development potential [10].

Although aluminum matrix composites strengthened by SiC particles have eminent application value in the field of aerospace, electronic packaging, and some other fields, the problem is that this kind of material could not be fabricated easily. It has a wide range of practical significance for us to do research on SiC<sub>p</sub>/Al matrix composites in grinding performance, because grinding has some advantages like high machining accuracy, less material consumption, integrated machined surface, and low grinding surface roughness [11-13].

In the aluminum matrix composite, the SiC particles have characteristics of high elastic modulus and wear resistance [14]. The aluminum matrix composites which are prepared under low pressure have some shortcomings, like low relative density, many internal cavities, and unevenly distributed

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silicon carbide [15, 16], where all of these would affect the quality of grinding surface. In order to solve these problems, high pressure sintering method is applied in this study to prepare SiC<sub>p</sub>/Al composites [17]. The grinding performance of SiC<sub>p</sub>/Al matrix composites will be studied by analyzing the grinding morphology and grinding mechanism under the preparation condition of different pressures, temperatures and volume fractions [18].

## 2 Experimental methods

These SiC particles whose content of SiC is about 96% were used as reinforcement materials which were produced by Zhengzhou Deli Company. The particle size, density, and melting point of the irregular, light green SiC particles are 20 μm, 3.2 g/cm<sup>3</sup> and 2700 °C respectively. The atomized ZL101A powders and passivation nano-aluminum powders were chosen as aluminum matrix. Passivated nano-aluminum powders were produced by Jiaozuo Banlv Na-no Material Engineering Company Limited, the particle size of ZL101A powder is between 150 μm and 212 μm, while the size of the black nano-aluminum powder is 80 nm.

Table.1 The preparation conditions of SiC<sub>p</sub>/Al samples

	Volume fraction (Vol-%)	Pressure (GPa)	Temperature (°C)
1#	20	4.6	500
2#	40	3.0	500
3#	40	3.8	500
4#	40	4.6	500
5#	60	4.6	500
6#	60	4.6	620
7#	60	4.6	740

The “Nano-aluminum-SiC” blending powder had been used in making SiC<sub>p</sub>/Al composites. The SiC particles were surrounded by a layer of nano-aluminum powders, which can reduce the agglomeration of the SiC particles. The SiC<sub>p</sub>/Al composites were prepared with conditions of different volume fractions, pressures, and temperatures by the method of high-pressure sintering with six-face presser machine, as shown in the Table 1. For this purpose, the density and

hardness of SiC<sub>p</sub>/Al composites will be improved, which can show superior grinding performance. The grinding experiment of SiC<sub>p</sub>/Al matrix composites were tested by the two-dimensional vertical grinding test equipments. An iron plate of 140mm×30mm×15mm in size was adopted to splice all samples. Two grain sizes of 500# and 110# of grinding wheel were chosen to do the grinding experiment at the rotating velocity of 600 m/min, reciprocating speed of 20 m/min on the surface of samples under dry condition. After the grinding tests had been undergone for 10 min, all samples were cleaned up and dried. The grinding property of SiC<sub>p</sub>/Al matrix composites were analyzed through the SEM micrographs of grinding surface morphology.

## 3 The results and discussion

### 3.1 The effect of different volume fractions of SiC on the grinding performance

Fig. 1 shows the microscopic images of SiC<sub>p</sub>/Al matrix composite material with volume fraction of SiC of 20%, 40% and 60% respectively, which were obtained at the same temperature and pressure condition of 500 °C and 4.6 GPa.

The grinding of SiC<sub>p</sub>/Al matrix composites sample under the volume fraction of 20% was smoother as shown in the Fig 1. in Here shallow furrow stripes appeared and grinding marks of 40% volume fraction SiC<sub>p</sub>/Al matrix composites bend. Al alloy matrix was ductile cut and extrusion was coated on a workpiece surface due to the increase of the SiC particles hindering grinding, while the 60% volume fraction SiC<sub>p</sub>/Al matrix composites material showed good grinding property. Grinding scratches just existed in the aluminum matrix, and the grinding marks were not observed in other distribution of the SiC particles.

Furthermore, it can be seen from the Fig 2(a) that some SiC particles were pulled out after grinding and forming some SiC particles grooves [19], as shown in position 1 of the Fig 2(a). There also appeared flaking pits in the position 2 of the Fig 2(a) which shows that the composites appeared peel adhesion in the grinding process [20, 21]. The same phenomenon also appeared in the 40% volume fraction SiC<sub>p</sub>/Al matrix composites material, as shown in the position 3 of Fig 2(b). However, the number of these grooves had reduced significantly

comparing them to the former grinding surface. For the 60% volume fraction SiC<sub>p</sub>/Al matrix composites material, the volume fraction of SiC particles was bigger than of the alloy matrix, so these SiC particles cannot be better encapsulated. Weak bonding strength and defects existed the two-phase

interface, resulting in the SiC particles brittle fracture or exfoliation under the influence of impact, shear, and extrusion of the grinding wheel grain. Some large area exfoliated pits of the SiC particles and voids had been observed as shown in the Fig 8(c), and the grinding surface became rough.

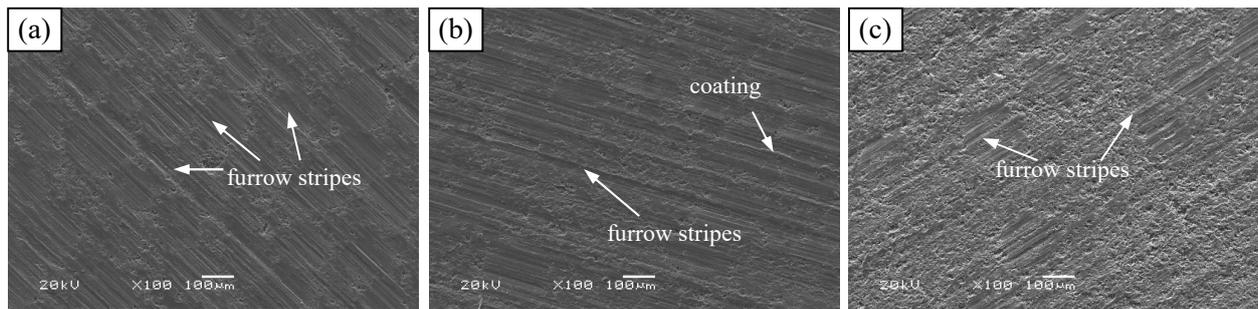


Figure 1. Grinding scanned photos under the condition of: (a)20%-4.6 GPa-500 °C, (b)40%-4.6 GPa-500 °C and (c)60%-4.6 GPa-500 °C

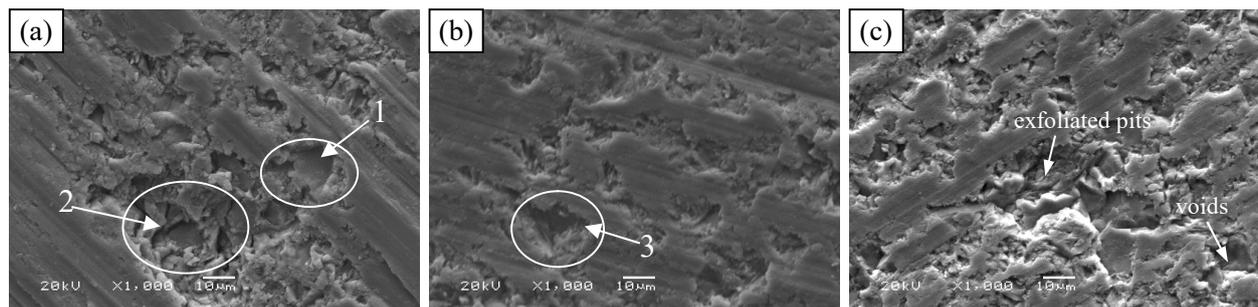


Figure 2. Grinding scanned photos under the condition of: (a)20%-4.6 GPa-500 °C, (b)40%-4.6 GPa-500 °C and (c)60%-4.6 GPa-500 °C

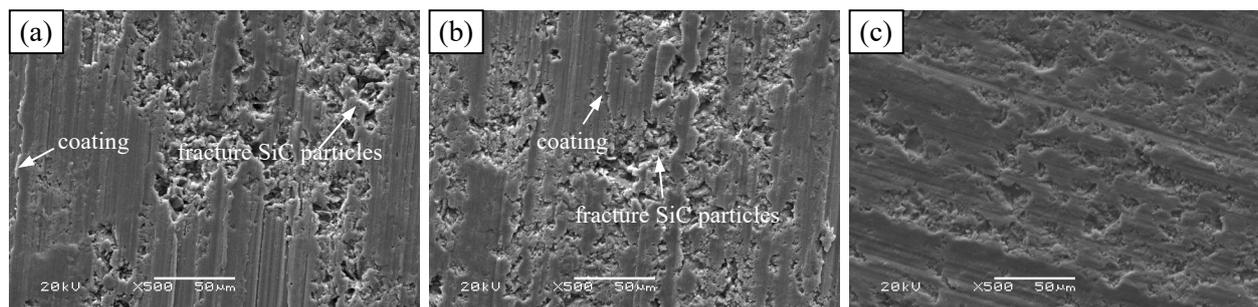


Figure 3. Grinding scanned photos under the condition of:(a)3.0 GPa-40%-500 °C, (b)3.8 GPa-40%-500 °C and (c)4.6 GPa-40%-500 °C

### 3.2 The Effect of preparation pressure on the grinding performance of composites

Fig. 3 shows the microscopic images of SiC<sub>p</sub>/Al matrix composite material with pressure condition of SiC of 3.0 GPa, 3.8 GPa and 4.6 GPa

respectively, which were obtained at the same volume fraction and temperature of 60% and 500 °C.

It can be seen from the Fig 3. that the surface morphology after grinding under the pressure of 4.6GPa was superior to other pressures, and the

grinding morphology under 3.0 GPa and 3.8 GPa was slightly inferior. Many SiC particles peeled from the substrate easily and some fractured. The SiC particles had been pressed into the surface, as it is presented in the Fig. 3(a) and Fig. 3(b). This happened due to the weak bonding strength between Al alloy matrix and the SiC particles being under low preparation pressure. This shows that the grinding performance will be improved with an increase of preparation pressure.

### 3.3 The effect of preparation temperature on the grinding performance of composites

Fig. 4 shows the microscopic images of SiC<sub>p</sub>/Al matrix composite material with temperature of SiC of 500 °C, 620 °C and 740 °C respectively, which were obtained at the same volume fraction and pressure condition of 60% and 4.6 GPa.

The metal matrix composites reinforced by the high volume fraction from the SiC particles can be prepared by the high-pressure method easily comparing a powder metallurgy and stirring casting [22].

Fig. 4 showed that some SiC particles had peeled off the aluminum matrix under the grinding force, while some grooves of different sizes were formed. The less volume fraction of aluminum matrix results. The combined area and binding force between silicon carbide particles and aluminum matrix are small in the reinforced aluminum matrix composite of high volume fraction of the SiC particles. Therefore, the reinforced particles cannot be fixed well. At last, the SiC particles will be grounded easily during the grinding process. The Al alloy matrix would become soft and would get

higher deformation resistance with the increasing of temperature. In this way the voids between particles can be filled with the softening Al matrix, and the compactness of composite can be promoted. The composite would have a better property to resist the grinding of the grinding wheel grain. large amount of exfoliated pits can be seen in the Fig 5(a), which led to the appearance of an uneven surface of the composites. The number of exfoliated pits reduced slightly under the sintering temperature of 620 °C, as shown in the Fig. 5(b). When the sintering temperature reached 740 °C, scratches on samples were shallower and exfoliated pits distributed, which can be observed in the Fig. 5(c). When the composites were achieved under the maximum volume fraction, the pressure and temperature of 60%, 4.6 GPa and 740 °C, the content of silicon was higher than aluminum as shown in the Fig 5. This is consistent with the volume fraction of the SiC particles being that the weight percentage of Si element is six times greater of Al element in the Fig. 5(b).

Fig. 6 is the SEM micrographs of grinding surface morphology of the sample 1# under different wheel grain sizes of 110# and 500#.

Fig. 6(a) indicates that some slight grinding marks had appeared, a few spherical grindings can be seen on the surface of organization. As shown in the Fig. 6(b), it can be observed that the scratches and abscission pits of the SiC reinforced particles had appeared on the surface of the SiC<sub>p</sub>/Al matrix composites material with the increase of grain size, while these grinding scratches were shallow, and no large area of the enhanced matrix abscission pits appeared.

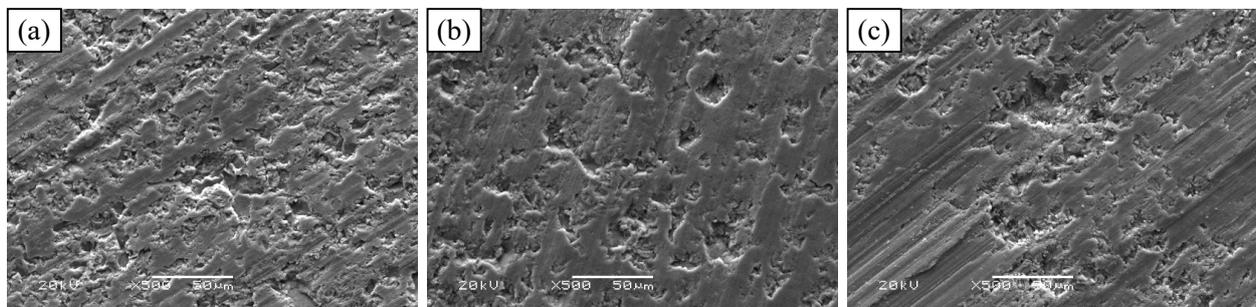


Figure 4. Grinding scanned photos under the condition of: (a) 500 °C -60%-4.6 GPa, (b) 620 °C -60%-4.6 GPa and (c) 740 °C -60%-4.6 GPa

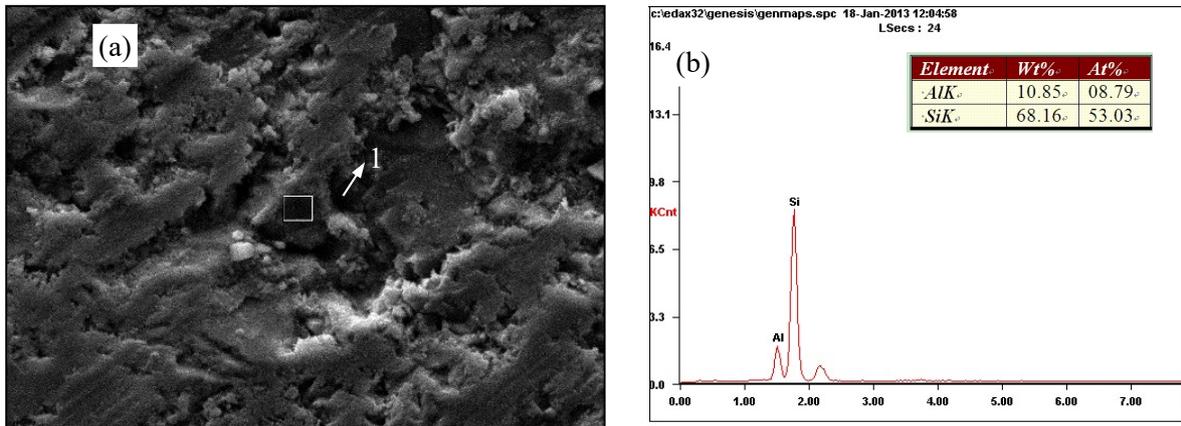


Figure 5. Regional scanning graphs (a) SEM micrographs (b) EDS analysis of region-1

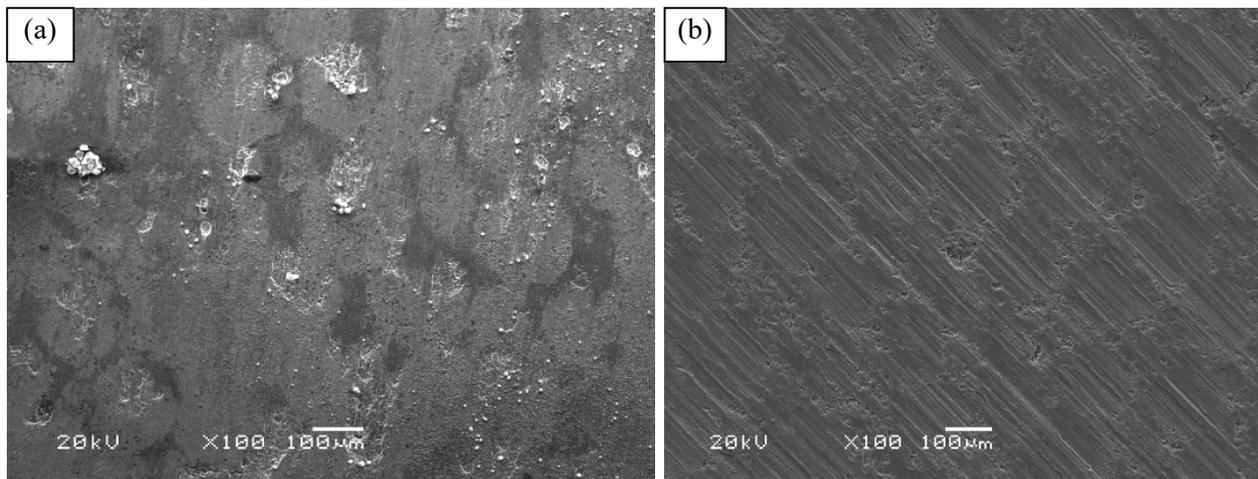


Figure 6. SEM micrographs of grinding surface morphology of the samples under different grain size conditions of: (a) grinding surface morphology of 500# grain and (b) grinding surface morphology of 110# grain

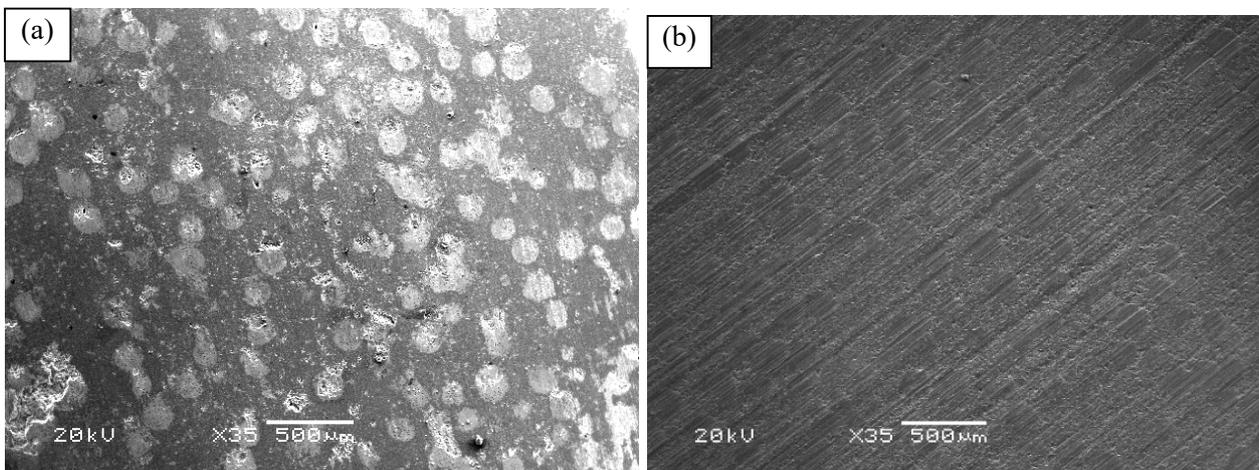


Figure 7. SEM micrographs of grinding surface morphology of the high volume fraction samples under different grain size conditions of: (a) grinding surface morphology of 500# grain and (b) grinding surface morphology of 110# grain

Fig. 7 is the SEM micrographs of grinding surface morphology of sample 6# that SiC<sub>p</sub>/Al matrix composite with SiC volume fraction of 60% under different wheel grain sizes of 110# and 500#.

It is obvious from the Fig. 7(a) that only some small abscission pits of reinforced particles had appeared on the surface of the SiC<sub>p</sub>/Al matrix composites with the SiC volume fraction of 60% after being ground by the 500# grinding wheel. Due to the content of the SiC reinforced particles being high, and aluminum matrix content relatively low, this led to the combined strength of reinforcement not being stronger than the low volume fraction composites. The reinforced SiC particles of high volume fraction SiC<sub>p</sub>/Al matrix composites can reduce grinding damage under the condition of the grinding wheel grain 110#, as shown in the Fig. 7(b). The grinding morphology was better than the low volume fraction composite, just some shallow scratches appeared during the grinding process. The grinding surface of the grinding wheel grain 110# was much rougher than 500#.

Different grinding characteristics of high pressure sintering of SiC<sub>p</sub>/Al matrix composites can be found in the Fig. 6 and the Fig. 7 under the different grinding wheel grain sizes. The samples showed better grinding ability when ground by the smaller wheel grain. The reason for this phenomenon is that the grain size of 500# reaches 20 μm, and the SiC particles size is 20 μm, so these SiC particles cannot be pulled out easily. When grinding process of 110# grinding wheel with the grain size of 135 μm happened, these SiC particles would be pulled out or broken quickly, while Al matrix would present furrow stripes under the grinding force.

#### 4 Conclusion

(1) When the content of SiC<sub>p</sub> is very low, some SiC particles are pulled out after grinding and some SiC particles form grooves; the grinding of SiC<sub>p</sub>/Al matrix composites under the volume fraction of 20% is more smooth, and some shallow furrow stripes have appeared; due to the high content of the SiC particles hindering the grinding process, the grinding marks of 40% volume fraction SiC<sub>p</sub>/Al matrix composites appeared bending compared with the low volume fraction SiC<sub>p</sub>/Al matrix composites; while the 60% volume fraction SiC<sub>p</sub>/Al matrix composites show good grinding resistance, the grinding scratches exists just in the aluminum

matrix, and the other parts of the SiC particles don't leave obvious grinding marks. Adhesion spalling has occurred during the grinding process; the grinding performance at the same temperature, and pressure conditions of 500 °C and 4.6 GPa is superior to the other grinding pressure and temperature conditions.

(2) Due to the volume fraction of the aluminum matrix in 60% volume fraction of the SiC<sub>p</sub>/Al matrix composites are less, which leads to the combined area and binding force between silicon carbide particles and aluminum matrix being small, and the reinforced particles cannot be fixed well, so the SiC particles will be ground easily during the grinding process. The grinding performance of high volume fraction of the SiC<sub>p</sub>/Al matrix composite is superior to the low volume fraction of the SiC<sub>p</sub>/Al matrix composite under the same conditions of the grinding wheel grain size.

(3) With the increase of the wheel grain size, the scratches and abscission pits of reinforced SiC particles happen on the surface of the SiC<sub>p</sub>/Al matrix composites, while these grinding scratches are shallow. No large area of the enhanced matrix abscission pits are found.

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