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Solidification simulation of a SiC_p/Al disk brake casting

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A SiC_p/Al composite disk brake casting for a high-speed application is produced using an adjustable vacuum pressure casting method specially developed for the production of SiCp/Al composite castings with complex structure. Feeding path during the solidification process of the disk brake casting is investigated by solidification simulation with a ProCAST code and checked by measurement of cooling curves. The simulation results match well with the measured cooling curves, which shows that the results of solidification simulation can be well used for a SiCp/Al composite casting production. With the help of solidification simulation, it is easy to establish a suitable feeding path that is the key technology for producing sound castings with the adjustable vacuum pressure casting method. Different casting plans with gating systems and chills are simulated and an improved casting plan for the disk brake casting is proposed based on the research presented in this paper. The casting quality is checked and confirmed by X-ray inspection and destructive inspection, which shows that the casting has few internal defects.

Key words: SiC_p/Al composite disk brake, Vacuum adjustable pressure casting, Solidification simulation, Non destructive and destructive inspections.

Introduction

Brake components and systems are critical to ensure the safety of high-speed trains. With increasing speed, it is important to reduce the axel weight, especially the unsprung weight. Disk brakes that are an indispensable part for high-speed trains are installed on the axles and belong to the unsprung weight. Lightweight disk brake applied to high-speed trains can reduce the unsprung weight effectively, which is of great significance to the development of high-speed trains.

SiC particle reinforced aluminum matrix composites (SiC_p/Al) possess many advantages such as high specific strength and stiffness, low density, good thermal conductivity and wear resistance, which makes it a new potential material to produce disk brakes for high speed trains. However, it is difficult to produce sound SiCp/Al disk brake castings because of the poor casting property of SiCp/Al composites and relatively complex structure of disk brakes. Therefore, a suitable casting technology should be established to solve this problem. The adjustable vacuum pressure casting method developed at Beijing Jiaotong University is used here to produce disk brakes [1, 2].

The feeding path is a key technology for producing a sound casting in foundry production. However, it is difficult to establish an effective feeding path in traditional foundry technology. Lot of time has to be spent on experiments in order to establish a suitable feeding path. With the fast development of numerical technology, solidification simulation has been introduced to traditional foundry technology for simulating the temperature distribution of steel, iron and aluminum castings during their solidification processes [3-9] and an effective feeding path can be easily established according to the temperature distribution in a casting. There are few investigations on the solidification simulation of SiC_p/Al castings until now. In the paper presented here, the temperature distribution field of SiC_p/Al disk brake is simulated with the ProCAST code in order to establish a suitable feeding path and obtain the technology for a sound SiC_p/Al disk brake casting.

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SiC_p/Al Disk Brake Casting Process

An adjustable vacuum pressure casting method was developed for producing disk brake castings. The working pressure curve of the method is shown in Fig. 1. It can be seen that the method mainly consists of 5 steps in the casting process. Figure 2 is a model of the disk brake casting with the gating system. Liquid metal rose up into the mold cavity through a connection tube between the crucible and vacuum chamber under a pressure difference between the crucible and vacuum chamber where the sand mold is held. Then the pressure difference is increased to feed the casting through the feeding path in gating system and the casting. The melt solidifies under pressure and sound castings can be obtained successfully. It can be seen that a key technology is to establish a suitable feeding path in the

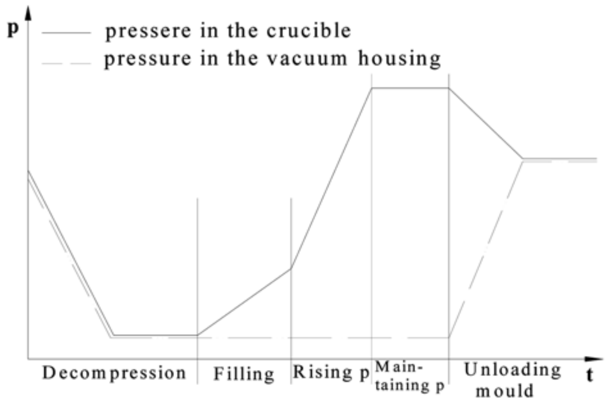

Fig. 1. pressure curve of adjustable vacuum pressure casting method.

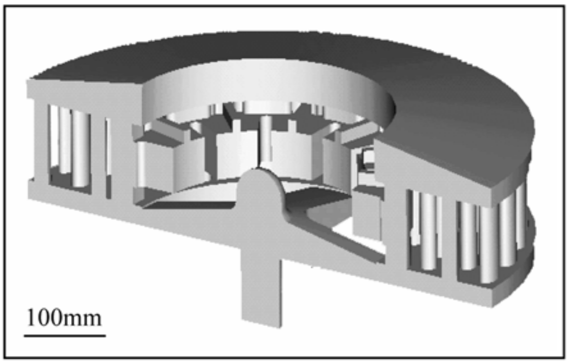

Fig. 2. Model of disk brake casting.

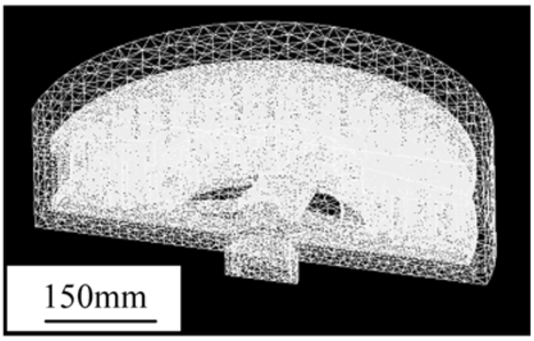

Fig. 3. Surface mesh of disk brake.

casting process.

3D-model and mesh selection of the disk brake

A 3D-model of the disk brake was built with the commercial Pro-engineer code. Half of the disk as shown in Fig. 2 is built for the simulation because of the symmetry of the disk brake casting. The mesh is divided automatically by the ProCAST code and meets the requirement of thermal conductivity and the accuracy of simulation. Surface and body meshes are shown in Fig. 3 and Fig. 4 respectively.

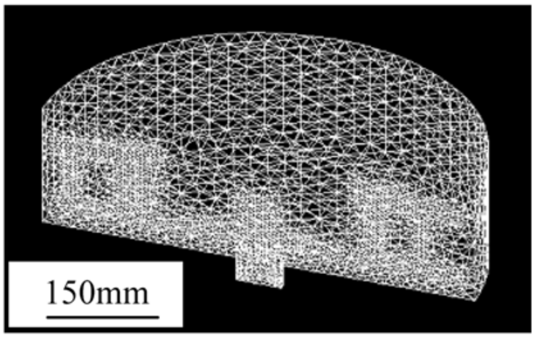

Fig. 4. Body mesh of disk brake.

Material Properties and Initial Conditions for the Simulation

The material of the disk brake castings was a SiC_p/Al composite and a resin sand mold was adopted. The primary parameters used in the simulation include specific heat, thermal conductivity, density, latent heat, solidus and liquidus temperatures. The physical properties of the SiC_p/Al composite and resin sand at different temperatures are shown in Tables 1 and 2. The initial temperature of the sand mold was assigned at 303 K and the initial temperature of the connection tube was 593 K. The pouring temperature was 958 K.

Simulation Results

After the thermal physical parameters and the boundary conditions are determined, simulation can be preceded with ProCAST code. 8 points as shown in Fig. 5

Table 2. Physical properties of resin sand

Temperature [K]	298	473	673	873	1073
Conductivity [W/mK]	0.733	0.64	0.586	0.59	0.64
Specific heat [J/kgK]	676	858	993	1074	1123

Table 1. Physical properties of SiC particle reinforced aluminum matrix composite

Temperature K	Conductivity W/(mK)	Specific heat J/(kgK)	density kg/m^3	latent kJ/kg	solidus K	liquidus K
523	135	997				
623	142	1130				
723	156	1250	2790	279	571	615
823	162	1308				
923	152	1367				

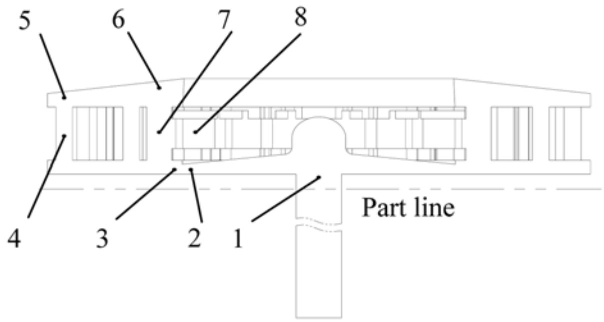

Fig. 5. Sketch map of alternative nodes used to measure temperatures.

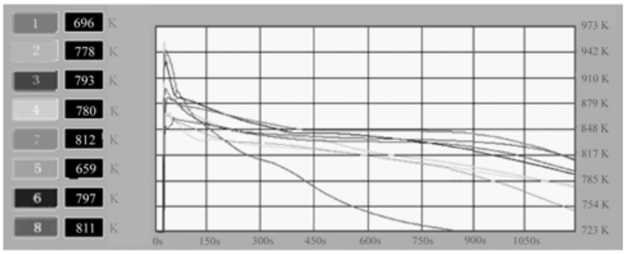

Fig. 6. Practical cooling curves.

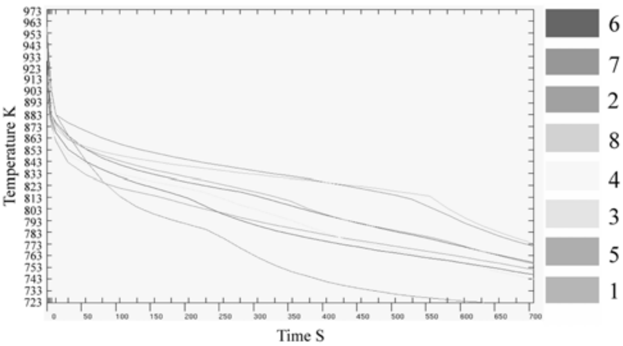

Fig. 7. Simulated cooling curves.

were selected to calculate their cooling temperatures in order to find an effective feeding path. Their practical cooling temperatures are measured in order to check the correctness of the simulated results against with the practical ones.

Figure 6 shows the cooing curves measured at the 8 points selected as shown in Fig. 5. Figure 7 shows the simulated cooling curves at the same 8 points. It can be seen that the calculated and measured cooling curves are very similar, which indicates that the solidification simulation is believable and can be used to describe the practical casting solidification process.

Both cooling curves of Fig. 6 and Fig. 7 show that point 1 cools faster than the other points, which indicates that there is no feeding path during the solidification process. That means there will be no melt to feed the cavity caused by solidification shrinkage when the inner side of the casting solidifies. Therefore porosity will occur in the casting.

Based on the simulation results and the problem found in the casting process, a new plan as shown in Fig. 8 was proposed to improve the solidification sequence. It can be seen that the diameter of the sprue is increased from 54 mm to 80 mm and also the ingate dimension is increased from 60×16 mm to 80×20 mm. A chill is placed to rapidly cool the hot spot position.

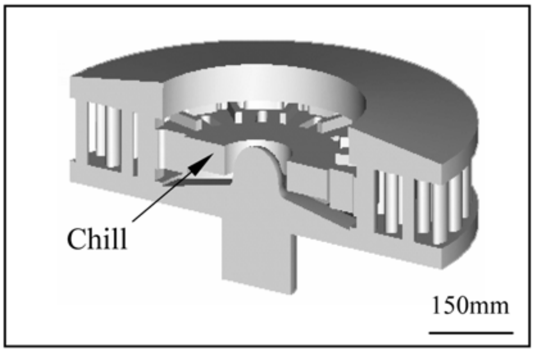

Fig. 8. Improved 3D-model of disk brake.

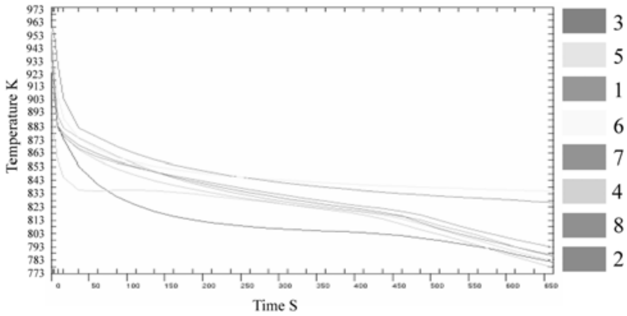

Fig. 9. Simulated cooling curves based on new casting plan.

Another run of simulation is carried out with the same material and initial parameters used in the previous simulation. The simulated cooling curves based on the new casting plan are shown in Fig. 9.

It can be seen from Fig. 9 that the solidifying

Fig. 10. Disk brake fracture.

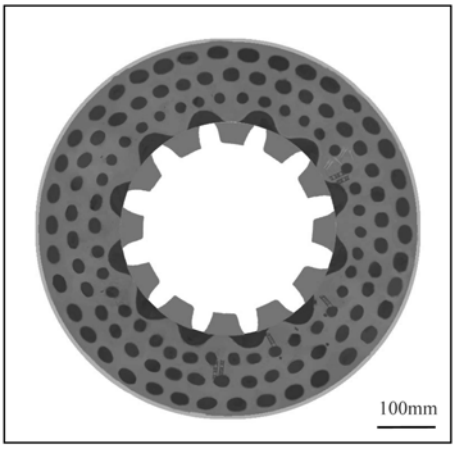

Fig. 11. Picture of X-ray inspection.

sequence is reasonable with the new casting plan. That means the disk brake casting solidifies in an early to late sequence shown as the points 4, 8, 5, 6, 7, 3, 2 and 1. An effective feeding path and gating systems during the solidification process have been established in the casting with the help of simulation technology.

Destructive and Non-destructive Inspection Results

A disk brake casting sample made of the SiC_p/Al composite was produced according to the new casting plan. The destructive inspection result is shown in Fig. 10 and the X-ray inspection result is shown in Fig. 11. It can be seen that there is little shrinkage inside the casting.

Conclusions

Solidification simulation can be used for a SiC_p/Al composite casting with a proper selection of material thermal properties. With the help of solidification simulation, an effective feeding path can be established in the adjustable vacuum pressure casting method and a sound SiCp/Al disk brake casting can be produced.

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