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Rapid Manufacturing of Sand Molds by Direct Milling*

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Abstract: Direct milling of sand molds is an important development in rapid manufacturing of sand molds. Direct milling is an effective method for manufacturing single or small batches of cast parts. This paper describes experimental investigations to find sand blocks with the appropriate strength, to describe wear patterns of different tools (high-speed steel (HSS), carbide, and polycrystalline diamond (PCD) tools), and to analyze sand mold cutting mechanisms. The results show that the PCD tool outperformes the other tools in terms of tool life. Average flank wear and micro-tipping are the dominant tool failure modes in the sand mold milling process. With a flank wear limit of 0.3 mm, the PCD tool works continuously for about 70 h under the experimental conditions. The experimental results show that the cutting mechanism for direct milling sand molds differs from metal cutting.

Key words: milling sand molds; tool-wear; rapid manufacturing; cutting mechanism

Introduction

Casting has been extensively applied in various industries, enabling rapid development of non-ferrous castings for automobile, aviation, and aerospace. However, traditional production methods for large quantities of casting molds are not cost-effective, not flexible and enegy intensive due to the conventional moulding or core-making method. Moreover, analyses show that the moulding and core-making processes create 30%-60% of casting defects critical to high-quality castings[1]. As a result, casting mold production plays an important role in casting fabrication. Genarally, casting mold production can be divided into conventional methods based on dies and rapid sand mold manufacturing based on layered manufacturing methods[2-4]. Although rapid prototyping methods make the process easier and more accurate, these methods are still more time consuming than desired or have practicality limitations. In addition, many of these methods only produce prototypes of wax, plastic, or paper/wood, which are insufficient for most laboratory testing[5-8]. For manufacturing, component samples must be verified before full production to reduce lead times and costs. The development cycle can generally be categorized into conceptual modeling, detailed design, prototyping/testing, manufacturing, and product release. Changes in the conceptual modeling stage are cheapest, while changes at the product release stage are most expensive[6-8]. Therefore, the quicker a prototype can be used in testing or verification, the more changes a manufacturer can make before it is manufactured or released to the marketplace. Thus, new mold making methods are needed that do not require high manufacturing speeds.

With the development of numerical control (NC) technology, directly milling has been used to create sand molds of castings which are adapted to a competitive environment and are bringing momentous

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changes in foundries. This method, which avoids mould making, eliminates work steps, and reduces allowances, is suitable for single and mini-batch casting production, especially for fabrication of large castings. Some companies, for example ACTECH and METROM, have applied this technology to production. The Advanced Manufacture Technology Center of China Academy of Machinery Science & Technology (CAMTC) has also created a forming machine that produces high quality sand molds.

1 Experimental Procedure

The purpose of the experimental work was to observe the tool wear behavior of different cutting tools and to study the mechanisms for milling sand molds. Washed silica sand with a binder and ester curing agent was used as the experimental materials. The silica sand properties are listed in Table 1. The properties of the binder, a new colorless, tasteless, and pollution free water-glass are listed in Table 2. The ester curing agent properties are given in Table 3.

Table 1 Properties of silica sand

Designation	Particle (order)	SiO_2 (%)	Acid (%)	Coefficient of angularity
ZGS90-21Q-30	50/100	90	4.0	1.2
ZGS85-15Q-30	70/140	88	4.0	1.2

Table 2 Sodium silicate binder properties

Designation	Viscosity (Pa•s)	Density (g/cm^3)	Fe (%)	Insoluble (%)
HYT S-101	⩽350	1.40-1.56	⩽0.05	⩽0.6

Table 3 Ester curing agent properties

Designation	Viscosity (Pa•s)	Density (g/cm^3)	Free acid (%)
HYT G-132	⩽100	1.10-1.20	⩽2

The experimental equipment consisted of a three-axis milling machine, a blowing sand system, CAD software, and an NC system. The machining range was 800 mm×600 mm×250 mm. The axis location error was ±0.05/300 mm and the reposition error was ±0.03 mm/full-stroke. The high-speed steel (HSS), carbide and polycrystalline diamond (PCD) tools were used for the milling.

The milling sand mold tests were conducted in three steps.

(1) The sand block was prepared by first premixing the silica sand and the water-glass binder for 40 s and then for 30 s with the ester curing agent. Then, the mixture was poured into a 260 mm×260 mm×50 mm moulding flask to form a sand block.

(2) The hour and the final strength of a standard tensile and a compressive sample were measured on a hydraulic strength testing machine.

(3) The sand mold was then measured to evaluate the tool wear. The flank wear on the tools was measured after certain machining intervals using a measuring microscope. The wear criterion was flank wear (VB = 300 μm) corresponding to an edge decline of 0.03 mm. The worn region of the tool was also analyzed.

2 Experimental Results and Discussion

2.1 Sand block strength

Figure 1 shows the tensile strength as a function of curing time for water-glass/silica sand ratios of 2.5% or 3% and curing agent/water-glass ratios of 15% or 20%. The compressive strengths were shown in Fig. 2. The tensile strength ranges from 0.4-0.55 MPa while the compressive strength reaches 2.7-3.1 MPa with

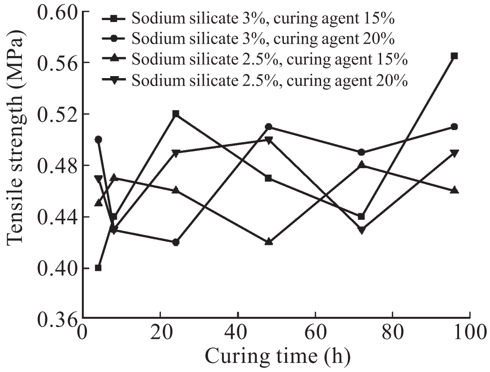

Fig. 1 Tensile strength of sand block

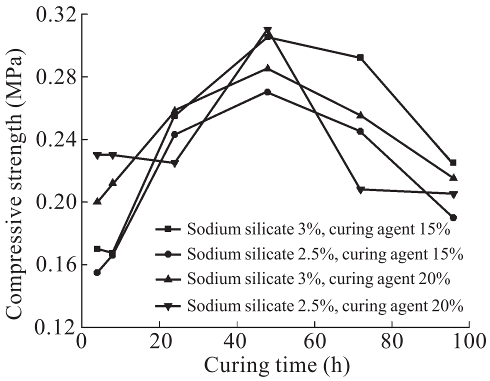

Fig. 2 Compressive strength of the sand block