A scaffolding architecture for conformal cooling design in rapid plastic injection moulding

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Abstract Cooling design of plastic injection mould is important because it not only affects part quality but also the injection moulding cycle time. Traditional injection mould cooling layout is based on a conventional machining process. As the conventional drilling method limits the geometric complexity of the cooling layout, the mobility of cooling fluid within the injection mould is confined. Advanced rapid tooling technologies based on solid freeform fabrications have been exploited to provide a time-effective solution for low-volume production. In addition, research has made attempts to incorporate conformal cooling channel in different rapid tooling technologies. However, the cooling performance does not meet the mould engineer’s expectations. This paper proposes a novel scaffold cooling for the design of a more conformal and hence more uniform cooling channel. CAD model for constructing the scaffolding structure is examined and cooling performances are validated by computer-aided engineering (CAE) and computer fluid dynamics (CFD) analysis.

Keywords Conformal cooling · Scaffolding · Rapid tooling · Plastic injection moulding

1 Background on cooling channel design in plastic injection mould

In recent years, rapid prototyping and tooling [1] processes have found widespread use in speeding up tooling production. These processes greatly reduce the manufacturing cost and the lead time required for tool production. Figure 1 illustrates the difference between traditional tooling production and contemporary rapid tooling fabrication.

1.1 Conventional cooling channel in plastic injection mould

The use of conventional cooling channel [2] allows coolant or water to circulate within the injection mould, removing the heat by dissipation. It is the most common method of controlling mould temperature. The channel is formed by hole-drilling in various sizes as close as possible to the actual moulding area of the cavity sets. Figures 2 and 3 illustrate the conventional cooling channel in the injection mould. According to the part dimensional accuracy required, the drilled holes are always machined using boring tool or drilling machine. The side wall of the mould is plugged and coolant is directed into cross bores and changed in direction. The freeform geometric cavity is surrounded by a straight-line cooling pattern. This will cause uneven cooling in the mould part. The uneven cooling will result in a tendency of several mould defects occurrence and increase the cooling time. A more acceptable cooling method is performed by the coolant flows in a pattern that closely matches the geometry of the part being moulded.

2 Conformal cooling channel in rapid soft tooling formed by copper duct

Conformal cooling [4] is defined as the cooling channels that conform to the surface of the mould cavity (or core) for effectively transferring the heat from the mould cavity to
the coolant channel. The term conformal means that the geometry of the cooling channel follows the mould surface geometry. The aim is to maintain a steady and uniform cooling performance for the moulding part. Figures 4 and 5 illustrate the geometries of the different conformal cooling channels.

From experimental results by several researchers, the injection mould cooling performance after utilizing conformal cooling channels can offer nearer uniform temperature distribution within the mould than the traditional cooling method. Heat can be evenly transferred or dissipated through the conformal cooling channel. Figures 6 and 7 illustrate the conformal cooling channel of direct AIM prototype tooling, designed by 3D Systems in 1997 [5]. However, the geometry of the copper duct can only partially follow the shape of the moulding part. It cannot provide a true uniform temperature distribution in the injection mould. The bending of the copper duct is limited by its diameter, mechanical strength and the size of the moulding part. Further bending of the copper duct will damage the cooling channel. It is worth to focus on the relationship between the geometry of the moulding surface and the cooling channel. The technique shown in Figs. 6 and 7 is proposed to realize the conformal cooling channel with better cooling performance.

Besides, properties like thermal conductivity and coefficient of thermal expansion are important in the rapid tooling process. Thermal conductivity is the quantity of heat transmitted through a distance in a direction normal to a surface with a certain area due to a temperature difference. An increase in thermal conductivity of the mould shortens the time required to cool down the moulding part. As epoxy is the material having low thermal conductivity, aluminium filler is added or mixed with epoxy. On the contrary, the coefficient of thermal expansion is the fractional change in dimension (or length) of a material for a unit change in temperature. The value decreases when aluminium filled compounds are added. Aluminium filled epoxy have a better dimensional stability than unfilled epoxy for injection moulding in RT.

Table 1 indicates the coefficient of linear thermal expansion and thermal conductivity of various metal filled epoxies.