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Conformal bubbler cooling for molds by metal deposition process[☆]

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HIGHLIGHTS

- Mold design with conformal cooling have been developed.
- Simulations have been done to make mold hollow but strong enough for all forces.
- Manufacturability is tested using metal deposition technique.
- Temperature distributions are uniform over the mold surfaces from the tests.

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ABSTRACT

Molds with conformal bubbler cooling channels have been developed in order to reduce the cycle time of the plastic injection process, which in turn has increased the production rate. In addition, part warpage can be greatly reduced in the injection process because the temperature distribution is uniform over the mold surfaces. Molds with conformal cooling designs, however, are still limited to computer simulations for generating the cooling channels or calculating the cooling rates [1–4]. This is mainly because there is "virtually" no fabrication technique that can effectively make the complicated conformal cooling channels. Even though metal deposition processes have the potential to create such complex mold shapes, most of the metal deposition processes are still in the developmental stage in laboratories. Molds formed by some of the metal deposition processes are not suitable for real industry use because the costs are still too expensive. This paper describes how to create a mold with conformal bubbler cooling tunnels through a metal deposition process that can actually be used in plastic injection industries. Experiments are conducted to confirm the normal temperature distribution over the mold surfaces.

1. Introduction

Almost all moldmakers recognize that the heat removal process has a significant role in injection molding, both in the mold core and the mold cavity. Cooling for mold cavities is typically done by drilling "straight" cooling channels around the cavities. The cooling channel circuits are uniformly wrapped around the mold cavities as close as possible to the shapes of the parts.

For a mold core, on the other hand, moldmakers simply drill a hole (or holes) into the bottom of a core and insert either a bubbler or baffle cooling tube (or tubes), as shown in Fig. 1, in order to remove as much of the excess heat as possible from the core, resulting in uneven heat distribution over the core surface. The excess heat in the core has to be lowered to a certain temperature before the part can be safely ejected. The uneven heat distribution causes mold stress and the potential for part warping. A poorly cooled core and a longer cooling time are both expensive and wasteful.

Conformal cooling has been used for many years to get the cooling lines as close to the mold surface as possible [1–4]. Moving the cooling lines closer to the mold surface can reduce the cycle time and promote a more uniform cooling of the mold surface. Some moldmakers such as Innova, for example, built molds with conformal cooling by stacking slices of mold with cooling channels milled on each layer [5]. The cooling system complexity, however, is physically limited by the conventional fabrication capability.

Instead of plugging in the bubbler cooling tubes, cooling tunnels are added to the mold by keeping the mold wall thickness constant, as shown in Fig. 2. Web or ribs are added to the mold construction as well in order to withstand the forces or pressure on the mold surface and to prevent the deflection or displacement of the mold surface during the plastic injection cycle.

Obviously, this mold configuration cannot be made by any conventional fabrication methods. Material deposition processes

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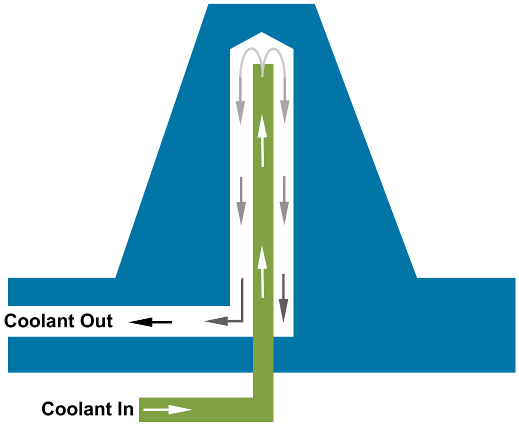


Fig. 1. Typical bubbler cooling for mold core.

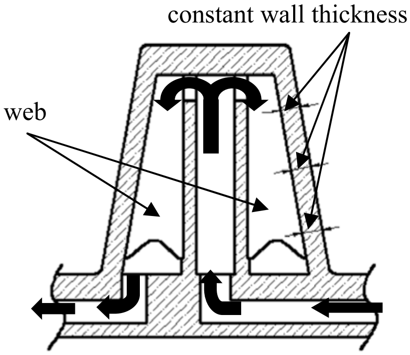


Fig. 2. Conformal bubbler cooling for mold core.

based on layered manufacturing techniques have proved to be an efficient approach to build complex molds directly from CAD models since its appearance in the mid 1980s. However, the non-metal layered manufacturing techniques such as SLA [6], FDM [7], and LOM [8] are not able to handle this job even though these techniques can create green parts with complex cooling channels. It is not an easy task to convert the green parts into metal molds. On the other hand, metal deposition techniques such as SLS [9,10], DMD [11], LAMP [12], and others, have the potential to fabricate these complex cooling tunnels inside the injection molds in order to improve the uniformity of cooling.

Nowadays, the cooling system designed for molds is still simple, being based on the moldmakers' experience and some simple formulas [13–16]. Simulations for mold cooling have received more and more attention from researchers since the early 1980s when scientific analysis was introduced into the injection molding industries [17]. Temperature distribution in the cooling stage is predicted by different proposed methods [18–27]. The residual stress, shrinkage and warpage are predetermined by simulation algorithms [28–35]. However, molds formed by current metal deposition processes are still not suitable for real industry uses.

2. Prior work

Similar to other metal deposition techniques, a MIG/MAG welding torch is attached onto a CNC machine in order to perform the additive process on the mold base as shown in Fig. 3. ER70S-6 wire (Ø1.2 mm) is used in this hybrid machine setup. After building up the mold configuration layer by layer, the mold surface is finished by milling, a subtractive process (Fig. 4) [36–42]. However, the material removal process can be done layer by layer along with the additive process if the shape of the mold is more complex.

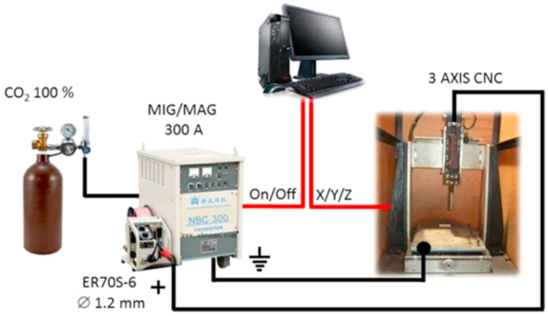


Fig. 3. Metal deposition process.

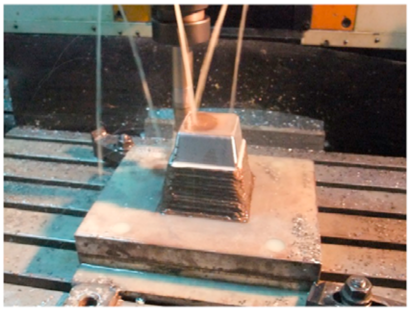
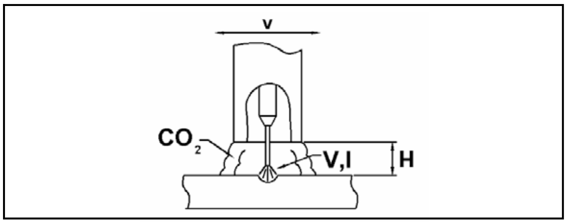
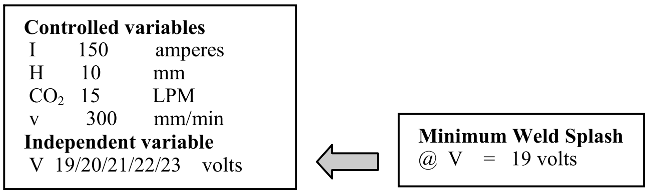


Fig. 4. Material removal process.



Parameters	Ranges
Current (I)	100 – 200 amperes
Voltage (V)	19 – 23 volts
Standoff Distance (H)	6 – 15 mm
Shielding Gas (CO$_2$)	10 – 25 litre/minute
Travel Speed (v)	200 – 500 mm/minute
Step Over (D)	1 – 5 mm
Deposition Path	Contour / Zigzag

Fig. 5. Parameters and suggested ranges.



Controlled variables

I	150	amperes
H	10	mm
CO$_2$	15	LPM
v	300	mm/min

Independent variable
V 19/20/21/22/23 volts

Minimum Weld Splash
@ V = 19 volts

Fig. 6. Vary voltages.

The suggested ranges of parameters are shown in Fig. 5, cultivated from literature searches [43]. A couple of steps based on the appearance of weld bead and the amount of weld splash, described in the following paragraphs, have been done in order to find an optimal set of parameters.

Firstly, voltage is alternated while other parameters are fixed. (Current: 150 amperes; standoff distance: 10 mm; Travel Speed: 300 mm/min; Shielding Gas Flow Rate: 15 l/min) By minimizing weld splash, 19 V is found to be the best voltage, as shown in Fig. 6.

Secondly, other parameters are fixed, as in the previous step, except the current. The voltage is also preset at 19 V. By varying

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