Microsystem Technologies 8 (2002) 55–57 © Springer-Verlag 2002
DOI 10.1007/s00542-001-0143-9

New plastification concepts for micro injection moulding

W. Michaeli, A. Spennemann, R. Gärtner

Abstract Until now there are no suitable injection moulding machines available for the production of single micro parts, so injection moulders produce big, but precise sprues to achieve the necessary shot weight. Very often over 90 % of the polymer are wasted and this waste can be an important cost factor. Moreover, the big sprue increases cooling time and, along with that, cycle time.

To open new dimensions for the minimum shot weight (<0.01 g), IKV, Aachen, Ferromatik Milacron Maschinenbau GmbH, Malterdingen, and Otto Männer Heißkanalsysteme GmbH, Bahlingen, with support of AGA Gas GmbH, Hamburg, have developed a new micro injection moulding machine.

The very small amount of plastics needed is plasticised in an electrically heated cylinder and fed into the injection cylinder by a plunger. A second plunger with a diameter of just 2 mm injects the molten material into the cavity. It is driven by an electric motor and a precise linear drive. A central element for the operation of the machine is the nozzle. It is heated electrically and can be cooled down rapidly by injecting liquid CO_2 (TOOLVAC technology). In this way the gate is closed after the injection and the holding phase. The moulded part can be demoulded and a new injection moulding cycle starts. This processing technology reduces the sprue to about 15 to 20 mg.

The ability to function of the thermal shut-off-nozzle could be proven theoretically by calculations with the IKV software CADMOULD/MEX. These calculations were verified by temperature measurements on a prototype machine. With the results of these investigations the design of nozzle and mould was optimized. After the injection unit and all the necessary drives and controlling devices have been integrated, the operation characteristics of the machine prototype are analysed.

In the next step of the project, the focus is on improving the plasticising efficiency, because the prototype is equipped with a simply electrically heated plastification. For the thermal layout of the plasticising unit the recently developed 3D software SIGMASOFT was used. Moreover, different plasticising concepts are analysed, as there are a "Weißenberg"-extruder using the normal stress effect or plastification by ultrasonics.

Especially the plastification by ultrasonics is a very promising idea for very small amounts of plastics and therefore analysed further. Ultrasonics are used successfully for welding and riveting in plastics processing, as it is fast and neat bondings are produced. A test unit was built to prove the ability to operate as a plasticising device and to optimize the necessary components and processing parameters. The plastification results regarding homogenization and morphology of the molten mass have been evaluated by microscopy.

The presentation will give detailed information about the trials and their results of the topics summed up above.

W. Michaeli, A. Spennemann, R. Gärtner (✉)
IKV, RWTH Aachen, Pontstrasse 49, D-52056 Aachen, Germany
E-mail: gaertner@ikv.rwth-aachen.de

The investigations set out in this report received financial support by the DFG (Deutsche Forschungsgemeinschaft), to whom we extend our thanks.

This paper was presented at the Conference of Micro System Technologies 2001 in March 2001.

1 Introduction

The injection moulding of microstructures represents a key technology for the economic production of medium and large series of microstructured mouldings and the assembly of micro-systems. During the last years fundamental research on the injection moulding of microstructures has been done at the Institute for Plastics Processing (IKV) at Aachen University of Technology (RWTH Aachen) [1].

But in micro injection moulding another task besides the injection moulding of small parts (>1 g) with microstructured details as often shown has to be considered: the direct production of micro parts, i.e. parts with a part weight down to a milligram (mg). Until now there are no suitable injection moulding machines available for the production of single micro parts, so injection moulders produce big, but precise sprues to achieve the necessary shot weight. Very often over 90% of the plastic material are wasted. Considering costs of up to $60 for 1 kg of special material e.g. for medical applications, this waste can be an important cost factor. Moreover, the big sprue increases cooling time and, along with that, cycle time.

2 Development of a new machine technology

Figure 1 gives an example for the described problem: the two parts shown are light guiding elements in the headlights of a Märklin Mini Club railway engine. Made from polymethylmethacrylate (PMMA) both of them together have a part weight of 0.033 g, but the shot weight including the sprue is 0.553 g, so that the weight of a single part is only about 3% of the total shot weight. The regrind of the sprue cannot be used for the same article, as the quality of

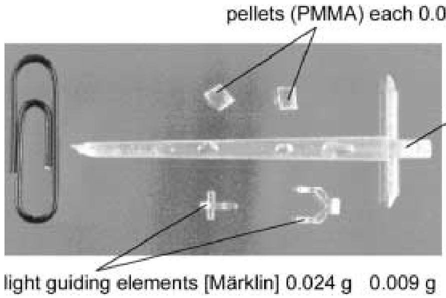

Fig. 1. Injection moulded micro parts

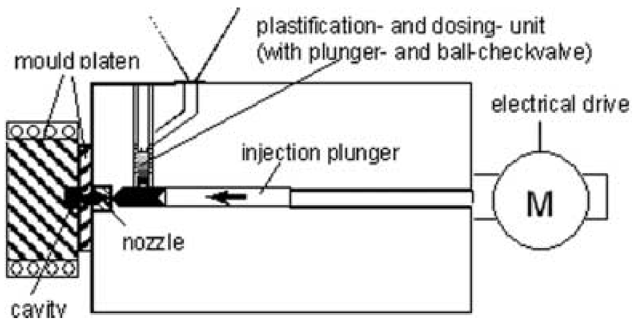

Fig. 2. Components of the micro injection moulding machine

the recycling material is not good enough for light guiding. So 94% of the material are wasted.

Figure 1 also illustrates the specific machine problems that come along with such small shot weights: the size of the plastic pellets used in standard injection moulding limits the size of the plastification screws to 14 mm diameter minimum, i.e. that when the screw moves just 1 mm, about 0.185 g of plastic material are injected. And even just one pellet of PMMA weighs 0.024 g, which is more than one of the parts shown in Fig. 1.

Until recently some machine builders offered modified standard machines with very small screws for the injection moulding of small parts from 5 to 0.5 g shot weight, but now new developments are in progress to reduce the shot weights [2–4]. Milligram parts were produced on the Plastics and Rubber Fair K '98 in Düsseldorf, but including the sprue shots weights were still about 0.01 g.

To open new dimensions in the size of minimum shot weight (<0.01 g), IKV, Ferromatik Milacron Maschinenbau GmbH and Otto Männer Heißkanalsysteme GmbH have developed a micro injection moulding machine that meets the moulder's demands. These demands were defined by reference moulders and by the experiences made during the process analyses carried out at the IKV during the last years [1, 7, 8]. The injection pressure varies between 150 and 600 bar. The cavity has to be evacuated to 0.5 bar to avoid burn marks and soiling. Mass temperatures go up to 400 °C for some engineering plastics. The mould tempering (fluid tempering) varies between 60 and 180 °C and an additional local heating of the cavity up to mass temperature has to be realized.

So the components of the new machine concept have to consider the following demands: the plastic material must not melt in the material feeding, but in a small metering zone to avoid material degradation. The dosing has to be controlled properly without soaking in air. A homogeneous

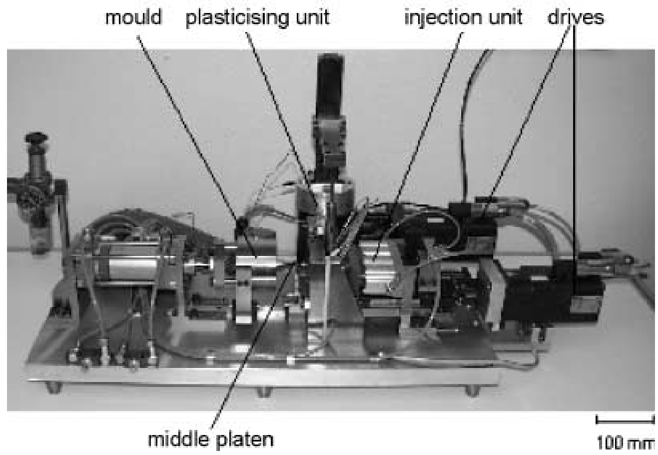

Fig. 3. Machine prototype

tempering of the plastification unit with a good thermal separation of nozzle and mould is important. For the injection of mg-shot weights the dosing has to be very exact and the material has to be injected fast and without leakage. All components should be dismantled and cleaned easily.

In the following the important elements and functions of the new machine and the injection moulding process are explained [5]. The most important elements (see Fig. 2) in this concept are a conical nozzle that is tempered separately and well insulated against the other machine components. The sprue plate is very narrow to keep the sprue volume as small as possible. The plate on the movable platen side transmits the clamping force onto sprue plate and nozzle.

The process starts with the injection of the molten mass into the cavity using an injection plunger (see Fig. 2). The plunger is driven by an electric motor. Nozzle and mould plates are heated up to the temperature of the molten mass. After injection, the holding pressure avoids shrinkage while the cavity is cooled and the plastics freezes. At the end of the holding phase, the nozzle is cooled down rapidly by the injection of liquid gas (CO_2), so that the mass in the nozzle freezes at once and shrinks. At this moment new molten mass can be metered. Then the sprue is ejected and teared off the molten mass in the cavity, while the moulded part is cooled down. To eject the part, the mould plates have to be opened. During ejection the mould plate is on the nozzle to heat up again and to hold back leaking melt. Then the mould closes and is heated up to the temperature of the molten mass. So the next production cycle can start. This processing technology reduces the sprue to about 5–15 mg.

After the ability to function could be proven theoretically, a prototype machine is built to verify the correct function of the machine elements in practical tests. Figure 3 gives a detailed example of the machine design [6]. The shape of the nozzle tip is a compromise between the minimization of the heat transfer between nozzle and mould during the processing cycle and a sufficient contact area for the centering and the absorption of the forces during injection. As the calculations have proven, that the moulded part can be cooled to ejection temperature using the TOOLVAC gate cooling, a fluid tempering system in the mould is not necessary. More important for a short

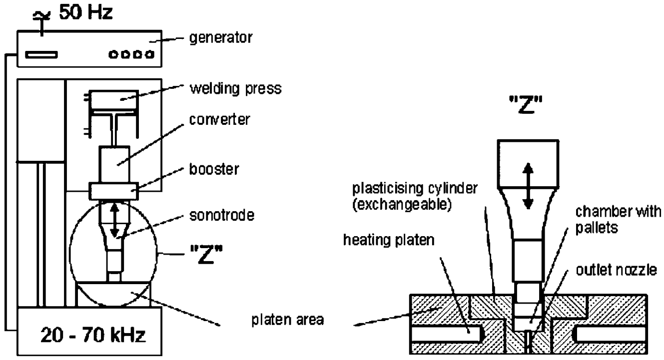

Fig. 4. Ultrasonic plastification system

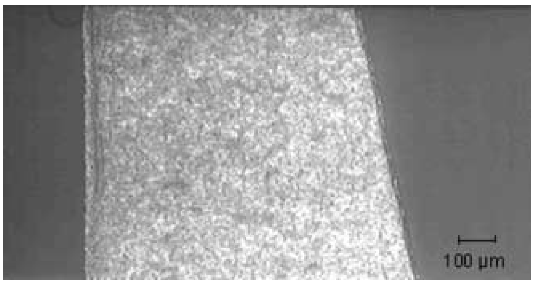

Fig. 5. Morphology of the molten mass plasticised by ultrasonics (POM)

cycle time is a sufficient heating system. A heater cartridge integrated in the mould insert decreases heating time.

Figure 3 also impressively illustrates the dimensions of the machine. The diameter of the injection plunger is 2 mm, whereas the dosing plunger has a diameter of 5 mm. For this reason the shot weight can be varied between 5 and 300 mg. The overall size of the machine excluding the drives is about the size of a shoe box and would fit onto a desk.

At the moment the very small amount of material is plasticised in an electrically heated cylinder, using a resistance heating system at the injection unit. With this kind of heating system it is possible to achieve three different zones in the plasticising unit called: solid-, metering- and melt zone. But the cycle time for producing micro parts depends basically on the dosing- and plastification time because of the poor heat conductivity of plastics. For this reason new plasticising concepts have to be found to increase the profitability by decreasing the plasticising time.

In the next step of the project, the focus is on improving the plasticising efficiency. A possibility to provide small amounts of melt can be realized by ultrasonic energy. Ultrasonics are used successfully for welding and riveting in plastics processing, as it is fast and neat bondings are produced. A test unit was built to prove the ability to operate as a plasticising device and to optimize the necessary components and processing parameters (see Fig. 4). In ultrasonic welding the heat is generated at the contact surfaces of the adherent parts. In micro injection moulding a defined amount of material must be plasticised quickly and homogeneously from a semi-finished product or pellets. After plastification, the melt can be injected by a special plunger or the ultrasonic sonotrode itself.

During the tests with this plastification system different machine parameters were measured e.g.: generator output, amplitude and way of the sonotrode, trigger power, holding pressure and temperature of the melt. To collect enough measuring data the plastification time was set to 5 s in the first tests. The amount of material plasticised during this time was five to six times higher than necessary for a typical micro part, so very short dosing times under 1 s could be achievable. The plastification results regarding homogenization and morphology of the molten mass have been evaluated by microscopy (see Fig. 5). As shown in Fig. 5 the material has crystallized very regularly with a homogenous structure.

3
Outlook

The investigations presented in this paper already show the immense potential of the new plastification concept using ultrasonics. The plastification concept developed for these analyses has proved its ability to function in first tests. The focus of the next step of the investigations is on further parameter measurement at the new plastification test-unit using different materials to prove the flexibility and efficiency of the method. High flexibility and efficiency is imperative not only for research constellations but especially for industrial applications. Another basic question in this research project is, how the plasticising by ultrasonics can be integrated into the given micro injection moulding machine or whether a newly designed device should be built considering the demands of ultrasonic technology.

References

1. **Rogalla A** (1998) Analyse des Spritzgießens mikrostrukturierter Bauteile aus Thermoplasten, Ph.D. Thesis, RWTH Aachen
2. **Götz W** (1998) Mikroteile in der halben Zykluszeit herstellen, Industrieanzeiger 18, pp. 40–41
3. **Kleinebrahm M** (1998) Der Weg zum Mikrospritzgießen. Proc. Micro Engineering '98, Stuttgart
4. **Kukla C; Loibl H; Detter H; Hannenheim W** (1998) Mikrospritzgießen – Ziele einer Projektpartnerschaft, Kunststoffe 88(9): 1331–1336
5. **Spennemann A; Zabold J; Lindner B; Koning E** (1998) Verfahren zum Spritzgießen von Mikroformteilen aus thermoplastischen Kunststoffen mit einer geringen Angußmasse, applied for patent, PA-No. 198.46.710.9, Deutsches Patentamt München
6. **Spennemann A** (2000) Eine neue Maschinen- und Verfahrenstechnik zum Spritzgießen von Mikrobauteilen, Ph.D. Thesis, RWTH Aachen
7. **Spennemann A; Michaeli W; Rogalla A** (1998) Process analysis of the injection moulding of microstructures, micro system technologies. 6th International Conference on Micro Electro, Opto, Mechanical Systems and Components, Potsdam, pp. 331–336
8. **Spennemann A; Michaeli W** (1999) Process analysis and machine technology for the injection molding of microstructures. Society of Plastics Engineers, ANTEC, New York