MATERIÁLY PRE KONŠTRUKCIU VSTREKOVACÍCH FORIEM

MATERIALS FOR INJECTION MOLDS PRODUCTION

Branislav DULEBA - František GREŠKOVIČ

Abstract

This contribution deals about possibility of production of injection mold from different materials. Nowadays selection of right material is consequential in terms of production rate and economics of manufacturing. Firs chapter describes the process cycle of injection molding and parts of injection mold. In next part of paper three different groups for production of molds are described with its pros and cons.

Key words

injection molding, injection molds, materials for molds

Introduction

Injection molding is one of the most widespread polymer processing technologies. It allows producing mould of both simple and complex form. Products made by injection molding are characterized by a very good dimensional and shape accuracy and high reproducibility of mechanical and physical properties. An advantage of injection molding is high efficiency of processed material, which ranks it among closed-cycle technologies. The quality of molded parts depends above all on the quality of the production tool, i.e. injection mould.

The main function of an injection mould is to give a processed polymer the required shape and cool it to the temperature that allows removing the molded part without any deformation. The shaped cavity is the most important for injection mould function. Its shape corresponds with the shape of the desired product; the dimensions differ only by the shrinkage value. Injection mould must conform to the *technical requirements*, which guarantee their correct function for the required number, quality and precision of moldings together with the *economic requirements* characterized by low acquisition price, easy and fast production and also high utilization efficiency of processed thermoplastics. Operation conditions of injection mould loading are as follows: injection pressure, tension, and wear intensity as well as higher temperatures of processed plastics including their chemical effects on functional surfaces.

1. INJECTION MOLDING

Injection molding is the most commonly used manufacturing process for the fabrication of plastic parts. A wide variety of products are manufactured using injection molding, which vary greatly in their size, complexity, and application. The injection molding process requires the use of an injection molding machine, raw plastic material, and a mold. The plastic is melted in the injection molding machine and then injected into the mold, where it cools and solidifies into the final part. Layout of classical injection molding machine is shown in Fig.1.

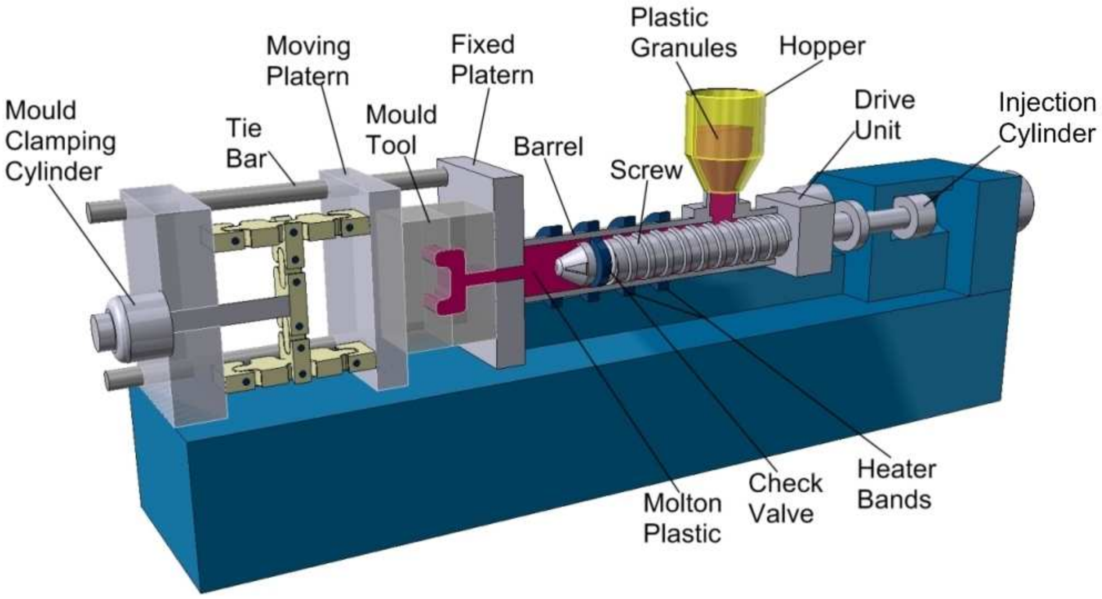

Fig. 1 Layout of injection molding machine

The process cycle for injection molding is very short, typically between 10 seconds and 2 minutes, and consists of the following four stages displayed on Fig.2:

Clamping - Prior to the injection of the material into the mold, the two halves of the mold must first be securely closed by the clamping unit. Each half of the mold is attached to the injection molding machine and one half is allowed to slide. The hydraulically powered clamping unit pushes the mold halves together and exerts sufficient force to keep the mold securely closed while the material is injected. The time required to close and clamp the mold is dependent upon the machine - larger machines (those with greater clamping forces) will require more time. This time can be estimated from the dry cycle time of the machine.
Injection - The raw plastic material, usually in the form of pellets, is fed into the injection molding machine, and advanced towards the mold by the injection unit. During this process, the material is melted by heat and pressure. The molten plastic is then injected into the mold very quickly and the buildup of pressure packs and holds the material. The amount of material that is injected is referred to as the shot. The injection time is difficult to calculate accurately due to the complex and changing flow of the molten plastic into the mold. However, the injection time can be estimated by the shot volume, injection pressure, and injection power.
Cooling - The molten plastic that is inside the mold begins to cool as soon as it makes contact with the interior mold surfaces. As the plastic cools, it will solidify into the shape of the desired part. However, during cooling some shrinkage of the part may occur. The packing of material in the injection stage allows additional material to flow into the mold and reduce the amount of visible shrinkage. The mold cannot be opened until the required cooling time has elapsed. The cooling time can be estimated from several thermodynamic properties of the plastic and the maximum wall thickness of the part.
Ejection - After sufficient time has passed, the cooled part may be ejected from the mold by the ejection system, which is attached to the rear half of the mold. When the mold is opened, a mechanism is used to push the part out of the mold. Force must be applied to eject the part because during cooling the part shrinks and adheres to the mold. In order to facilitate the ejection of the part, a mold release agent can be sprayed onto the surfaces of the mold cavity

prior to injection of the material. The time that is required to open the mold and eject the part can be estimated from the dry cycle time of the machine and should include time for the part to fall free of the mold. Once the part is ejected, the mold can be clamped shut for the next shot to be injected.

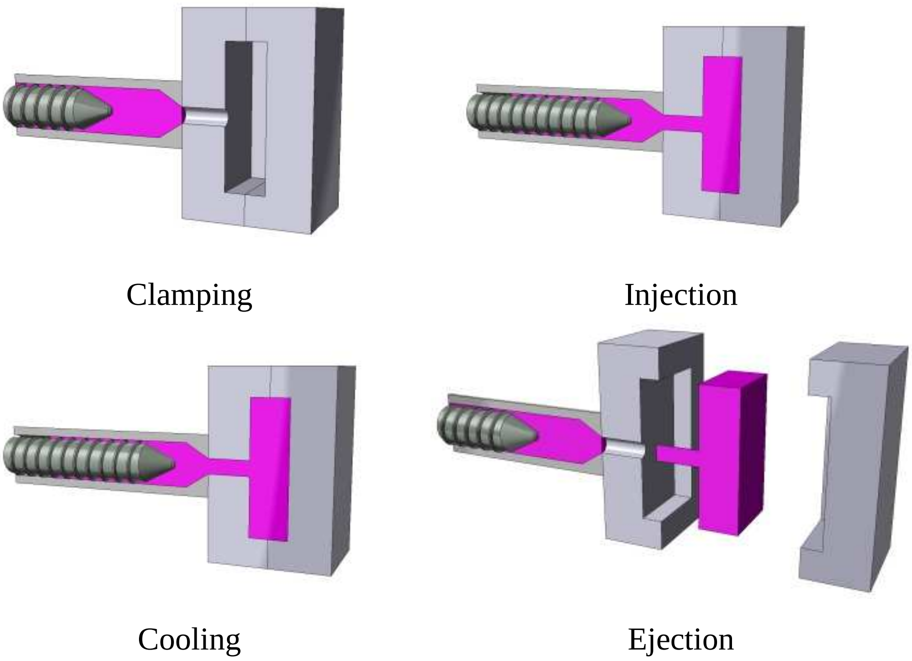

Fig. 2 The process cycle for injection molding

After the injection molding cycle, some post processing is typically required. During cooling, the material in the channels of the mold will solidify attached to the part. This excess material, along with any flash that has occurred, must be trimmed from the part, typically by using cutters. For some types of material, such as thermoplastics, the scrap material that results from this trimming can be recycled by being placed into a plastic grinder, also called regrind machines or granulators, which regrinds the scrap material into pellets. Due to some degradation of the material properties, the regrind must be mixed with raw material in the proper regrind ratio to be reused in the injection molding process.

2. INJECTION MOLD TOOLS

The injection molding process uses molds, typically made of steel or aluminium, as the custom tooling. The mold has many components, but can be split into two halves. Each half is attached inside the injection molding machine and the rear half is allowed to slide so that the mold can be opened and closed along the mold's parting line. The two main components of the mold are the mold core and the mold cavity. When the mold is closed, the space between the mold core and the mold cavity forms the part cavity that will be filled with molten plastic to create the desired part. Multiple-cavity molds are sometimes used, in which the two mold halves form several identical part cavities. Parts of molds are shown in Fig.3.

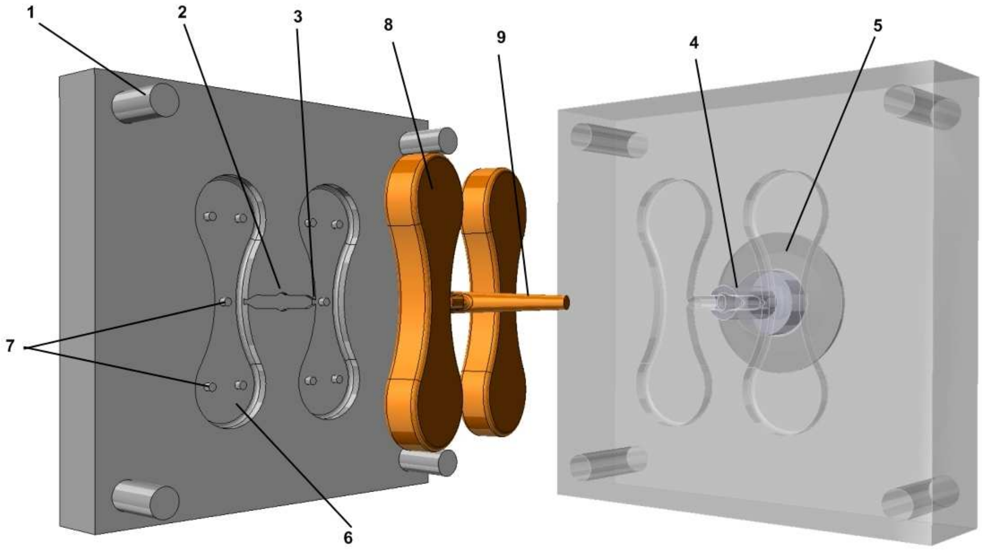

Fig. 3 Parts of injection molds

1. Guide Pins – fixed to one half of the mould and align the two halves by entering the holes in the other half.
2. Runner – passageways in the mould connecting the cavities to the sprue bush.
3. Gate – Frequently the runner narrows as it enters the mould cavity. This is called a gate and produces a weak point enabling the moulding to be easily broken or cut from the runner.
4. Sprue Bush – Tapered hole in the centre of the mould into which the molten plastic is first injected.
5. Locating Ring – Positions the mould on the fixed platen so that the injection nozzle lines up with the sprue bush.
6. Mould Cavity – The space in the mould shaped to produce the finished component(s).
7. Ejector Pins – These pins push the moulding and sprue/runner out of the mould.
8. The Shot – Total amount of plastic injected into mould.
9. Sprue – Material which sets in the sprue bush.

The mold core and mold cavity are each mounted to the mold base, which is then fixed to the platens inside the injection molding machine. The front half of the mold base includes a support plate, to which the mold cavity is attached, the sprue bushing, into which the material will flow from the nozzle, and a locating ring, in order to align the mold base with the nozzle. The rear half of the mold base includes the ejection system, to which the mold core is attached, and a support plate. When the clamping unit separates the mold halves, the ejector bar actuates the ejection system. The ejector bar pushes the ejector plate forward inside the ejector box, which in turn pushes the ejector pins into the molded part. The ejector pins push the solidified part out of the open mold cavity.

3. MATERIALS FOR INJECTION MOLDS

The injection molding technique has to meet the ever increasing demand for a high quality product (in terms of both consumption properties and geometry) that is still economically priced. This is feasible only if the molder can adequately control the molding process, if the configuration of the part is adapted to the characteristics of the molding material and the respective conversion technique, and a mold is available which satisfies the requirements for reproducible dimensional accuracy and surface quality. Therefore injection molds have to be made with the highest precision. They are expected to provide reliable and fully repeatable function in spite of being under extreme loads during the molding process, and a long service life to offset the high capital investment. Besides initial design and maintenance while in service, reliability and service life are primarily determined by the mold material used, its heat treatment and the machining operations during mold making.

Injection molding uses almost exclusively high-strength molds made of metals, primarily steel. While the frames are almost always made of steel, the cavities are frequently made of other high-quality materials - metals or nonmetals – and inserted into the cavity retainer plate. Inserts made of materials other than steel are preferably used for cavities that are difficult to shape. They are often made by electrodcposition. Recently, nonmetallic materials have been growing in importance in mold construction. This is due on the one hand to the use of new technologies, some of which are familiar from prototype production, and especially to the fact that users wish to obtain moldings as quickly and inexpensively as possible that have been produced in realistic series production, so that they can inspect them to rule out weaknesses in the product and problems during later production. The production of such prototype molds, which may also be used for small and medium-sized series, as well as the materials employed, will be discussed later.

An injection mold is generally assembled from a number of single components. Their functions within the mold call for specific properties and therefore appropriate selection of the right material. The forming parts, the cavity in connection with the core, provide configuration and surface texture. It stands to reason that these parts demand particular attention to material selection and handling.

Several factors determine the selection of materials for cavity and core. They result from economic considerations, nature and shape of the molding and its application, and from specific properties of the mold material. Details about the molded part should provide information concerning the plastic material to be employed (e.g. reinforced or unreinforced, tendency to decompose, etc.). They determine minimum cavity dimensions, wear of the mold under production conditions, and the quality demands on the molding with respect to dimensions and surface appearance. The market place determines the quantity of parts to be produced and thus the necessary service life as well as justifiable expenses for making the mold. The demands on the mold material, on its thermal, mechanical, and metallurgical properties are derived from these requirements. Frequently a compromise must he made between conflicting demands.

There are dozens of materials that can be used for making molds for producing plastic products, including many types of aluminum, brass and copper, epoxy, and many others, as well as combinations of these. The following section describes some of the more common materials and the role they play in the making of molds.

3.1 Steel molds

Normally, steel is the only material that guarantees reliably functioning molds with long service lives, provided that a suitable steel grade has been selected from the assortment offered by steel manufacturers and this grade has been treated so as to develop a structure that produces the properties required in use. This necessitates first of all a suitable chemical composition. The individual alloying elements, according to their amount, have positive as well as negative effects on the desired characteristics. Generally several alloying elements will be present, which can also mutually affect one another. The requirements result from the demands of the molder and the mold maker.

The following properties are expected from steels:

- characteristics permitting economical workability (machining, electric discharge machining, polishing, etching, possibly cold hobbing).
- capacity for heat treatment without problems.
- sufficient toughness and strength.
- resistance to heat and wear.
- high thermal conductivity, and
- corrosion resistance.

The surface contour is still mostly achieved by machining. This is time consuming and calls for expensive machine equipment and results in a surface quality which, in most cases, has to be improved by expensive manual labor. There are limitations to machining because of the mechanical properties of the machined material. Steels with a strength of 600 to 800 MPa can be economically machined although they are workable up to about 1500 MPa. Because a strength of less than 1200 MPa is generally not sufficient, steels have to be employed that are brought up to the desired strength level by additional treatment after machining, mostly by heat treatment such as hardening and tempering.

Such heat treatment imbues steels with the required properties, especially high surface hardness and sufficient core strength. Each heat treatment involves risks, though (distortion, cracking). Lest molds be rendered unusable by heat treatment, for those with large machined volumes and complex geometries, annealing for stress relief is suggested prior to the last machining step. Eventual dimensional changes from distortion can be remedied in the final step.

To avoid such difficulties steel manufacturers offer pre-hardened steels in a strength range between 1100 and 1400 MPa. They contain sulfur (between 0.06 and 0.10%) so that they can be machined at all. Uniform distribution of the sulfur is important. The higher sulfur content also causes a number of disadvantages, which may outweigh the advantage of better machining. High-sulfur steels cannot be polished as well as steel without sulfur. Electroplating for corrosion resistance (chromium, nickel) cannot be carried out without flaws. In the event of repair work, they cannot be satisfactorily welded and are not suited for chemical treatment such as photochemical etching for producing surface textures.

Types of steel for injection molds

1020 carbon steel. This steel is used for ejector plates and ejector retainer plates and is easily machined and welded. Not usually hardened because of distortion and warp, this material must be first carburized if hardening is preferred.

1030 carbon steel. Used for mold bases, ejector housings, and clamp plates, this steel has 25% greater tensile strength than 1020 and can be easily machined and welded. It can be hardened to Rockwell hardness C scale (R_c) 20 to 30.

1040 carbon steel. Commonly used for support pillars, this tough steel has good compressive strength and can be hardened to R_c 20 to 25.

4130 alloy steel. This is a high-strength steel used primarily for cavity and core retainer plates, support plates, and clamping plates, and is supplied at 26 to 35 R_c.
6145 alloy steel. Primary use for this type of steel is for sprue bushings and it is supplied at 42 to 48 R_c.
S-7 tool steel. Shock resistant with good wear resistance, this steel is used for interlocks and latches and hardened to 55 to 58 R_c .
O-1 tool steel. This is a general purpose, oil-hardening steel used for small inserts and cores and hardened to 56 to 62 R_c.
A-2 alloy tool steel. This steel has good dimensional stability and abrasion resistance, and is used for hobs and slides and is hardened to 55 to 58 R_c.
A-6 tool steel. A general purpose oil-hardening steel with good dimensional stability and high hardness, its primary use is for optical quality cavities and cores and it is hardened to 56 to 60 R_c.
D-2 tool steel. This steel has high chromium and high carbon content, and is difficult to grind, but has excellent abrasion resistance. It is used for gate inserts, lifters, and slides, and is hardened to 58 to 60 R_c .
H-I3 tool steel. This is a very high toughness, low-hardness steel used for high quality cavity and core requirements. It is primarily used for ejector pins, return pins, sprue pullers, leader pins, and slide-actuating angle pins, and supplied annealed at 15 to 20 R_c, but can be hardened to 60 R_c with little distortion.
P-20 tool steel. This is a modified 4130, commonly referred to as prehard. It is supplied at a R_c hardness of 28 to 40, which provides moderately high hardness, good machinability, and exceptional polishability. It is used primarily for cavities and cores, as well as stripper plates.
420 stainless steel. Used in applications requiring exceptional chemical resistance (such as molding PVC resins), this steel is usually supplied in an annealed condition (15 to 25 R_c), but can be hardened to 55 to 60 R_c. Its primary use is as a steel for cores and cavities.

3.2 Aluminum

While there are many grades of aluminum available for making molds, the most common, and most efficient to work with, is the aircraft grade 7075 (T6). This wrought aluminum alloy is produced by hot rolling cast aluminum to the desired thickness of plate. The entire mold can be made of the same material (including cavity and core) and an anodizing process can be utilized to impart a surface hardness of up to 65 R_c for wear resistance. However, due to the smoothing tendency of the normal aluminum surface, it is possible to mold with no surface treatment. The microscopic hills and valleys of the aluminum surface tend to even themselves out without galling. Use of 7075 aluminum can result in mold build times being reduced by up to 50% (due to faster machining times) and the injection molding cycle being reduced by up to 40% (due to faster heat dissipation), depending on size and complexity of the product being molded. Until recently, aluminum was considered as a mold making material only for low-volume production or prototype molds. The use of 7075 alloy has created opportunities to use aluminum for high-volume production in up to millions of cycles. Even glass-reinforced and high-temperature plastics can be molded successfully in aluminum molds.

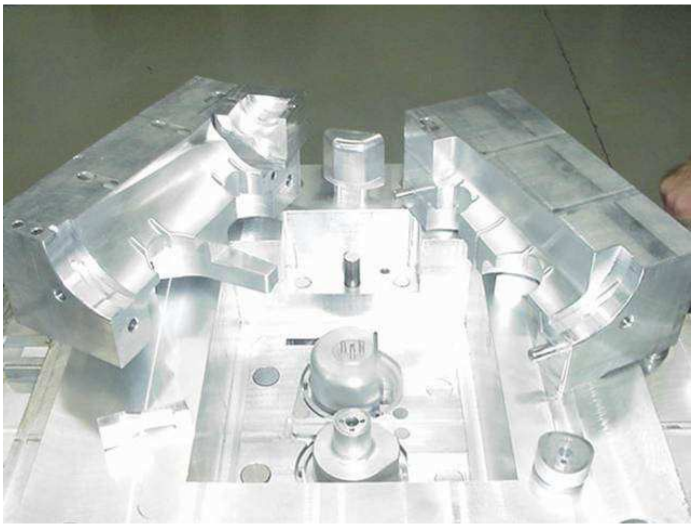

Fig.4 Aluminium prototype mold

3.3 Beryllium -copper Alloys

High strength and high levels of thermal conductivity make the beryllium-copper alloys excellent selections for making cores and cavities for injection molds. They are commonly used as components that are fitted to steel mold bases, but also can be used in conjunction with aluminum mold bases for greater economy. They are particularly useful for situations where the placement of cooling channels in the mold makes heat removal difficult, such as in deep draw parts or parts with unusual contours. Strategically placed beryllium-copper components will assist in dissipating the heat from these areas without using complicated water line channels.

The types of beryllium-copper most commonly used for cores and cavities arc CuBe 10, CuBe 20, and CuBe 275. They differ mainly in tensile strength with the higher numbers having the greater strength. In addition, the higher number grades allow higher levels of hardness. This ranges from a low of Rb 40 for CuBe 10 to a maximum of R 46 for CuBe 275.

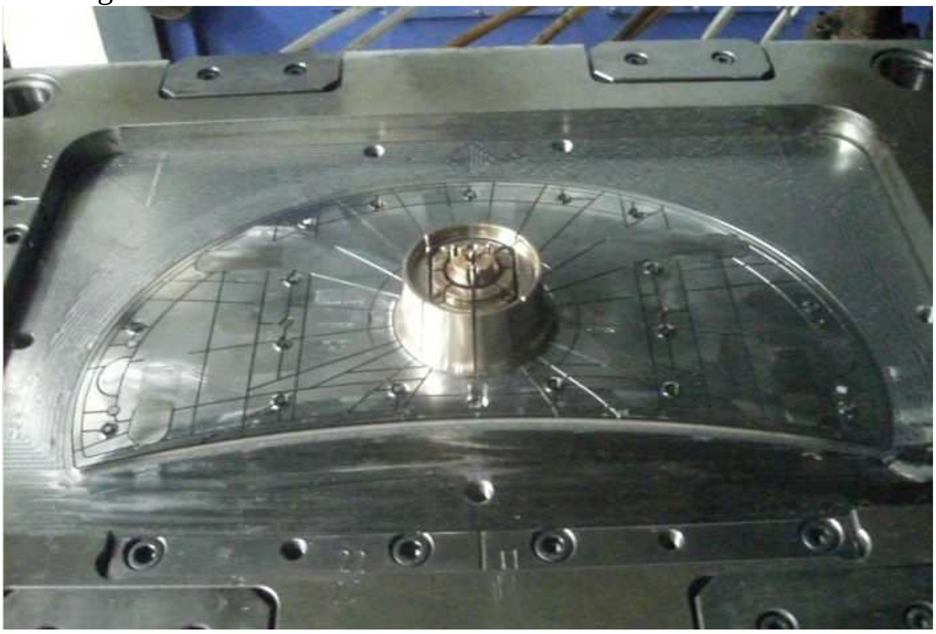

Fig.5 Beryllium-copper insert (yellow) on injection molding mold for ABS resin

3.4 Other Materials

There are other materials that can be used for making molds for plastic injection molding, including epoxy, aluminum/epoxy alloys, silicone rubbers, and even wood. However, these are usually all reserved for very small volumes, such as fewer than 100 pieces. In most cases, these represent prototype volumes, and the molds are not expected to meet the demanding requirements of higher-volume production levels. The scope of this type of mold construction does not fit the intent of this publication, and the reader requiring further information is encouraged to contact mold makers specializing in the prototype field.

Conclusion

The mold or die refers to the tooling used to produce plastic parts in molding. Traditionally injection molds have been expensive to manufacture and were only used in high-volume production applications where thousands of parts were produced. Molds are typically constructed from hardened steel, pre-hardened steel, aluminum, and/or beryllium-copper alloy. The choice of material to build a mold from is primarily one of economics. Steel molds generally cost more to construct but offer a longer lifespan that will offset the higher initial cost over a higher number of parts made before wearing out. Pre-hardened steel molds are less wear resistant and are primarilly used for lower volume requirements or larger components. The hardness of the pre-hardened steel measures typically 38-45 on the Rockwell-C scale. Hardened steel molds are heat treated after machining, making them superior in terms of wear resistance and lifespan. Typical hardness ranges between 50 and 60 Rockwell-C (HRC).

Aluminum molds cost substantially less than steel molds, and when higher grade aluminum such as QC-7 and QC-10 aircraft aluminum is used and machined with modern computerized equipment, they can be economical for molding hundreds of thousands of parts. Aluminum molds also offer quick turnaround and faster cycles because of better heat dissipation. They can also be coated for wear resistance to fiberglass reinforced materials. Beryllium copper is used in areas of the mold which require fast heat removal or areas that see the most shear heat generated.

Key words
injection molding, injection molds, materials for molds

Acknowledgements

This paper is the result of the project implementation: Technological and design aspects of extrusion and injection moulding of thermoplastic polymer composites and nanocomposites (PIRSES-GA-2010-269177) supported by The international project realized in range of Seventh Frame Programme of European Union (FP7), Marie Curie Actions, PEOPLE, International Research Staff Exchange Scheme (IRSES) and project APVV-0682-11.

Literature

[1] GREŠKOVIČ, F., et.al : Nástrojena spracovanie plastov– Vstrekovacie formy, ISBN 978-80-553-0350-5, TU Košice

[2] KAMAL, R.: Injection molding technology and Fundamentals. 1st ed. Munchen, Germany: Hanser Publications, 2009, ISBN: 978-3-446-41685-7

[3] OSSWALD, A.: Injection molding handbook, Hanser Verlag, Munich, 2008, ISBN 1569904200,

[4] REES, H: Mold Engineering, Hanser, Ontario, Canada, 2002, 678s, ISBN 3-446-21659-6

[5] ROSATO, D., DONALD, D.: Injection molding handbook, Norwell Massachusetts, Kluwer Academic Publishers, 2000, ISBN-10: 0792386191

[6] Shoemaker, J.: Moldflow Design Guide: A Resource for Plastics Engineers, Hanser Publishing, Massachusetts, 2006, ISBN: 9781569904039

Contact

Ing. Branislav Duleba
Technical University of Kosice, Faculty of mechanical engineering
Department of Technologies and Materials
Mäsiarska 74
040 01 Košice, Slovakia
e-mail: branislav.duleba@tuke.sk