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Design and Analysis of the Sleeve Ejection System in Injection Molding Die for Trolley Wheel

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Abstract: **Plastic is a commonly used engineering material. Properties like availability, less weight, moldability and corrosion resistance are a few among many desirable properties, due to which most of our usable products are made of plastic. This vital use encourages manufacturing industries to make plastic products in large scale. The industries are able to meet this demand and supply requirement, using various methods of processing plastics. All the methods and tools for processing plastics contribute to mass production. Injection molding dies are one among the many tools used for processing plastics to the required shape. Usually it is very easy to learn and perform the injection molding method to obtain plastic products. But to achieve quality components in mass production, one needs proper implementation of each die-set element in an injection molding die. Ejection of component from the die cavity is one phase in injection molding process and it has similar importance like all other phases. This paper aims at implementation of sleeve ejection system for plastic trolley wheels. Software used for modeling of parts is UG Nx 9.0 and that for the simulation of process parameters is Autodesk Moldflow Adviser 2015. Stress and deformation analysis is done by ANSYS 16.0 version.**

Index Terms: **Moldability, Mass Production, Tool, Plastic Mold, Die, Ejection, UG Nx 9.0, Autodesk Moldflow Adviser 2015**

I. Introduction

Injection molding process is similar to hot chamber die casting. A barrel (cylinder) is heated to promote melting. The pallets or granules are fed into the heated cylinder, and the melt is forced into a split-die chamber, either by hydraulic plunger or by the rotating screw system of an extruder [1]. This split-die is termed as injection molding die or mold. They are aligned and clamped together. This is the first phase of injection molding process, known as clamping. Pressurized flow of the plastic melt into the mold is another phase and this phase of the injection molding process is called as injection. After the die cavity is filled, it is allowed to cool for curing of plastic melt into shaped cavity of the mold, this phase is known as cooling. In the last phase of the process, molds are opened and the solidified part is ejected out of the mold cavity, thus this phase is called ejection [2]. This is the end of one cycle of the injection molding process. Molds are then closed again and the process is repeated. The process can be optimized by analyzing all the dependent and independent variables involved within [3].

An injection molding die is a systematic arrangement of a number of different parts or elements, assembled together to accomplish each phase without any error. Most of such elements were illustrated in Figure 1. To achieve mass production, time consumed by each phase is kept as small as possible. Thus, a designer plans and designs element for each phase effectively. There are different conditions and situations associated with each phase, which must be addressed wisely. The complexity related to ejection phase is slightly related to change of form of plastic material inside the mold cavity. As plastic solidifies in the mold cavity it shrinks on the core which forms it. This shrinkage makes the molding difficult to remove. Thus, there must be proper provision by which molded part can be positively ejected from the mold cavity. Such provision is called as ejector system and this is situated behind the fixed die block in an injection molding die set.

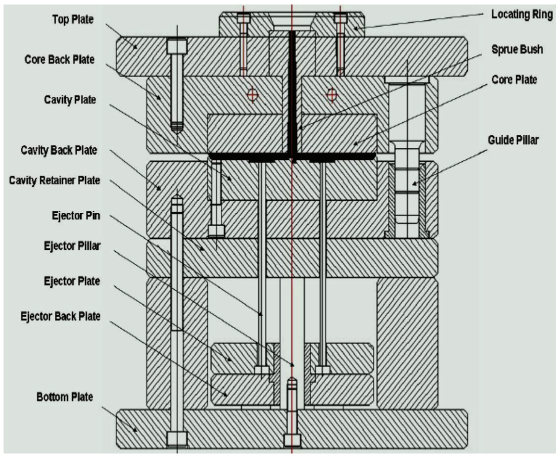

Figure 1. Elements of an Injection Molding Die
(Source: researchgate.net)

The design of an effective ejector system is planned in three parts viz. ejector grid, ejector plate assembly and method of ejection. Ejector grid is a part of the mold which supports the mold plate and provides sufficient space into which the ejector plate assembly can be fitted and operated. The ejector plate assembly is that part of the mold to which the ejector element is attached. The assembly is contained in a pocket, formed by the ejector grid, directly behind the mold plate. The method of ejection is about several ejection techniques by which a component can be ejected from the mold cavity [4]. Few basic ejection techniques are pin ejection, sleeve ejection, bar ejection, blade ejection, air ejection, stripper plate ejection etc. These ejectors remain hiding on mold surface till the phase of solidification. After solidification as the die opens, they advance to push the component away from the cavity. The selection of a suitable

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ejection technique depends mainly on the shape and size of molding. But one type of ejection technique is not restricted to be used in one particular type of molding [5]. Required strength, economy and easiness of manufacturing are among few other factors which must be considered before deciding the ejection technique. Due to ease in manufacturing and installation, pin ejectors are widely used in ejection technique. But a pin ejector usually leaves impression and sometimes additional material deposition called boss, on the surface of the component. Figure 2 represents one such component, trolley wheel. Ejector bosses can be easily seen on its surface. Such marks are usually undesirable, especially if the appearance of the component is an important aspect.

Figure 2. Ejection Marks of Pin Ejection on Trolley Wheel

Incorrect size and wearing, as well as chopping of the ejector pin tips cause such ejector marks and bosses. This is one of the limitations of the pin ejection system. Another aspect of avoiding pin ejection is related to strength, which can be observed from Figure 3. Ejectors need to apply ejection force on the solidified component in the mold cavity so that the component comes out of the cavity, overcoming the friction of mold walls and shrinkage on core. This force is distributed on the number of ejectors employed for ejection. Due to shape, size and available space constrains, less number of big size ejectors cannot be deployed. Thus, a number of small size ejectors are used for uniform ejection of the component. For their movement, holes are made in the mold and inserts. Higher number of ejectors implies to more number of holes in die, and inserts resulting a decrease in their strength.

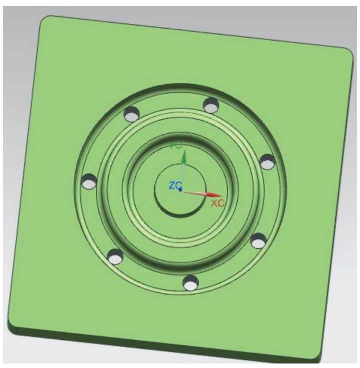

Figure 3. Holes in a Die for Pin Ejection

Proper product design along with correct study of shrinkage behavior of the components like trolley wheel indicates that a single sleeve ejector can be sufficient for such component rather than using multiple pin ejectors. In sleeve ejection method the molding is ejected by means of a hollow ejector pin, termed as sleeve. It is used preferably for circular moldings, moldings with usually local circular bosses and to provide ejection around a core pin forming a round hole in molding. This implementation not only decreases complexity in the die design but also contributes to low cost of die manufacturing.

II. Product Design

An effective mold design begins with proper product design of the part to be molded. In the product design phase a product is observed for its manufacturability by a particular process of manufacturing. By considering various design considerations and product specification a part was redesigned and corresponding to that its mold was prepared [6].The modeled product for this research work is as shown in Figure 4.

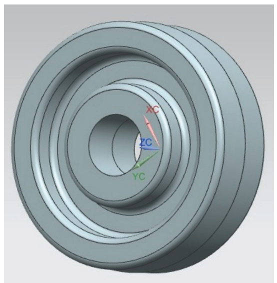

Figure 4. Modeled Trolley Wheel for Analysis

Figure 5 represents various dimensions and geometry of the component. The dimensions of the modeled product for this research work were taken from one of the standard dimension followed by the manufacturers. Then it was further modified by providing appropriate fillet and drafts in the direction of ejection. The component dimension was slightly modified in terms of hub diameter and mass reduction groove. Table I represents few specifications related to the modeled product.

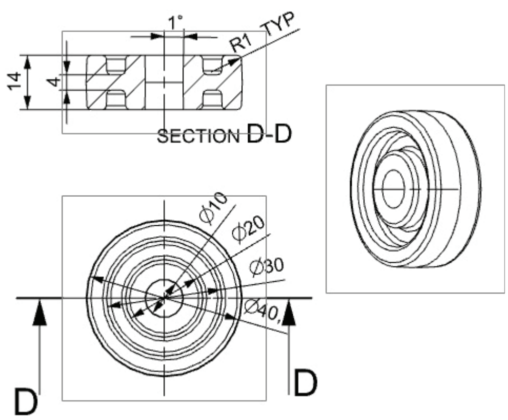

Figure 5. Dimensional Details of the Component
(All dimensions are in mm)

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TABLE I.
PRODUCT SPECIFICATION

Part Name	Trolley Wheel
Material	Polypropylene
Part Volume	12828.28 mm^3
Surface Area	8172 mm^2
Mass	15.4 gm

By observing geometry and profiles of the component, horizontal plane of symmetry was considered as parting plane. This arrangement of parting plane was suitable according to design considerations of designing of plastic molds. Thus the expected position of component against mold opening and closing is shown in Figure 6.

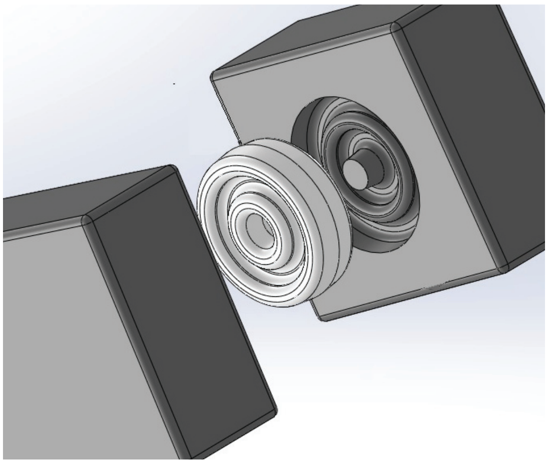

Figure 6. Position of the Component in Die and Expected Direction of Ejection

By the observation of the component profile, it can be understood that it has sufficient wide hub area near to the central hole. As the central hole is inbuilt profile of the component, cure pin will be implemented in the mold to achieve the hole in the component. Sufficient surface available in hub area can be used as resting area of ejector sleeve for sleeve ejection of the component. But before proceeding for designing of the ejection system, we should ensure that the phases prior to ejection are intact. Thus, we should see that the component is perfectly in condition prior to ejection. For this purpose we will perform simulation of injection molding for the component. Polypropylene is preferred for this purpose because it is one of the preferable materials for making trolley wheels. Few of the important characteristics of polypropylene (PP) are enlisted in Table II.

TABLE II.
MATERIAL SPECIFICATION
POLYPROPYLENE (PP)

Density	946 kg/m^3
Melting Point	160 °C
Formula	$(C_3H_6)_n$
Type	Thermoplastic
Flexural Strength	40 N/mm^2
Shrinkage	1-2.5% mm/mm
Tensile Strength	32 N/mm^2
Injection Temperature	140-160 °C
Heat Deflection Temperature	100 °C
Specific Gravity	0.91

For process parameter selection, specifications from an injection molding machine were taken. So that further trial results would be compared after development of such ejection system which we are being considered in this research article. Before starting simulation, it is always desirable to consider part shape, size material and machine capacity in to account [7]. Common specifications of available injection molding machine is shown in Table III.

TABLE III.
MACHINE SPECIFICATION
(TEXPLASST 1HD, PT LAB, CVRCE)

Shot Capacity	2 – 45 gms / shot
Plunger Diameter	25 mm
Stroke Lenght	450mm
Clamping Capacity	6.0 Tons
Injection Pressure	80 kg/cm^2
Heating Capacity	1.5 kw
Total Installed Power	3.7 kw
Total Shut Height	100 - 450mm

Based on above mentioned process parameters and material properties, process simulation was performed with help of Autodesk Moldflow Adviser 2015 software. The obtained results were indicated in Figure 7 and Figure 8. Confidence of fill indicates possibility of filling of die cavity in conventional injection molding conditions [8]. Weld lines emerges if there is no proper fusion of polymer flow front due to design features like, hole, ribs etc. [9]. Indicated and other obtained results clearly show that there is no defect in the component like weld line of air entrapment which may become problem for implementing sleeve ejection of the component.

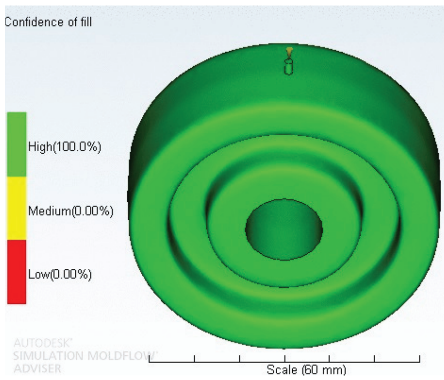

Figure 7. Confidence of Filling Prediction

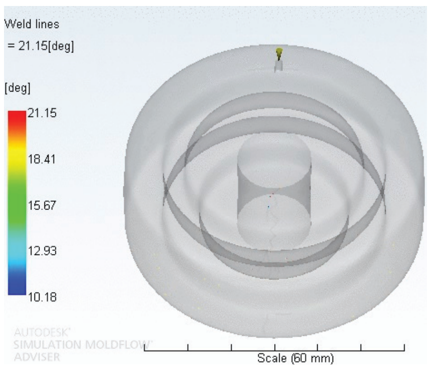

Figure 8. Weld Line Prediction

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III. Ejection Force Calculations and Sleeve Ejector Design

In molding, no part can be ejected from the mold cavity till it acquires sufficient rigidity. During solidification, polymer shrinks inside the mold and internal stress builds up [10]. The solidified component shrinks on the core or on the inserts. Thus an ejection system should overcome the frictional forces caused due to shrinkage [11].

A. Calculation of Ejector Force

To calculate ejection force, based on various material properties, an equation is developed by experiments [12], which is shown below.

$$Fe = \frac{\alpha\,(Tm - Te)EA\,\mu}{\left(\frac{D}{2t} - \frac{D\gamma}{4t}\right)} \qquad (1)$$

Where,

Fe = Ejection Force (N)
α = Coefficient of thermal expansion for molding material (/°C)
Tm = Melting temperature of molding material (°C)
Te = Ejection temperature of molding material (°C)
E = Young's modulus of material at Te (N/cm^2)
A = Area of contact between core and molding in direction of ejection (cm^2)
μ = Coefficient of friction between molding material and core material
D = Diameter of core (cm)
γ = Poisson's ratio of molding material
t = Thickness of mold (cm)

The required values of above mentioned parameters for our situation are collected from various sources and arranged in Table IV. Ejection temperature is taken as 20°C by considering the ideal condition that the mold is being cooled by cooling lines to reduce solidification time of the component.

TABLE IV.
Values of Parameters

α	$8 \text{ X } 10^{-5}$ cm (cm/°C), standard
Tm	152 °C, standard
Te	20 °C, standard
E	$1.32 \text{ X } 10^5$ N/ cm^2, standard
A	2.17 cm^2 from software
μ	0.3, standard
D	1 cm, measured
γ	0.42, standard
t	0.7 cm in one half, measured

$$Fe = \frac{8\times10^{-5}\times(152-20)\times1.32\times10^{5}\times2.17\times0.3}{\left(\frac{1}{2\times0.7}-\frac{1\times0.42}{4\times0.7}\right)}$$

$Fe = 1608\,N$ (Approximately)

B. Validation of Result

Thus approximately 1608 N force was required to push the component away from the cavity. As the maximum shrinkage was occurring on core and nearby area was also sufficient to implement ejector sleeve, we must check the possibility of damage in our component by this type of ejection. For this purpose ANSYS 16.0 version was used to analyze our component for any possibility of localized deformation on our component and result is displayed in Figure 9 and Figure 10. The component was fixed in core area and load of 1608 N if applied in distributed manner on hub area. As we can observe that negligible deformation has occurred, the result indicated that the component can be ejected by sleeve ejector.

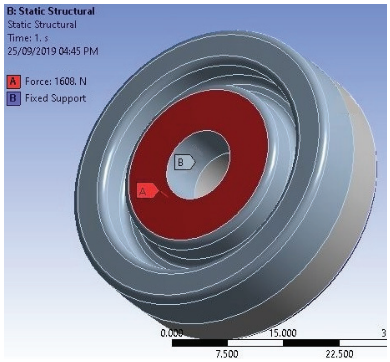

Figure 9. Applied Load Position

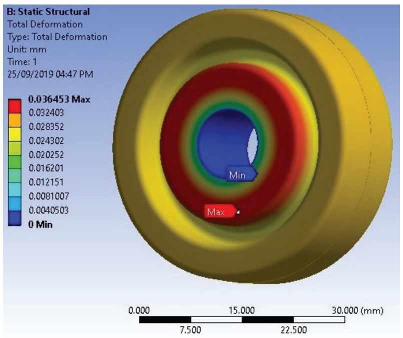

Figure 10. Effect of Ejection Force on Deformation Pattern of the Component

C. Design of Sleeve Ejector

Sleeve ejectors are always employed in two parts viz. core pin which is surrounded by ejector sleeve. They usually have common basic design but their dimensions and profiles can be specific based on particular application. Ejector sleeve and core pins generally have sliding fit [13]. This fit additionally acts as venting medium [14]. Inner diameter of core pin slides on outer surface of the core pin. Nitriding is done to harden them up to 65-70 HRC. Core hardness is usually kept in the range of 45-55 HRC. Otherwise due to wear, clearance will increase on contact surface causing flash in molding. Hot working tool steel is most proffered material used for making ejector sleeve. Overall manufacturing is possible by turning operations, for profiled heads milling is done. One possible design of ejector sleeve and core pin, corresponding to our requirement is shown in Figure 11 and in Figure 12 respectively.

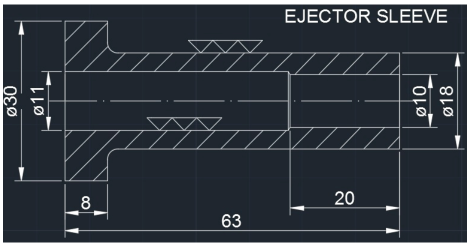

Figure 11. Ejector Sleeve
(All dimensions are in mm)

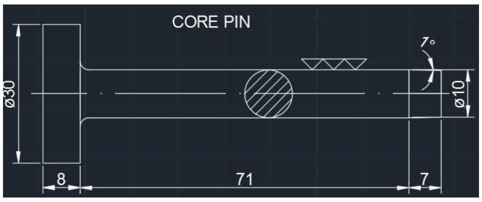

Figure 12. Core Pin
(All dimensions are in mm)

One can observe Figure 13 to understand the arrangement of sleeve ejector in combination with other parts of mold assembly. In this figure, part number 1 and 3 indicates ejector sleeve and core pin respectively. Part number 2 is mold plate. Part number 4 and 5 are ejection plates which cause sleeve to move during ejection. Part number 6 is termed as core retainer plate. Ejection gap is maintained as amount of travel of ejection plates. Usually it is kept more than the length of deepest cavity in the mold, so that the component can be fully pushed out of the mold cavity.

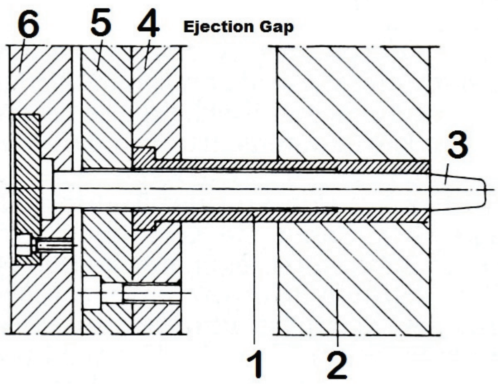

Figure 13. Ejector Assembly

IV. Ejection Simulation

When a number of movable parts come together, it is necessary to compare and observe their relative position and dimension. Assembly and simulation of sleeve ejector assembly is done with help of UG Nx 9.0 software.

A. Assembly

Figure 14 indicates partial assembly of sleeve ejection system along with component and mold inserts. For the sake of simplicity of observation, other plates, viz. die block, ejector plates etc are not shown. One can visualize top half and bottom half of die (kept transparent), component in die cavity, fixed core pin and sleeve ejector.

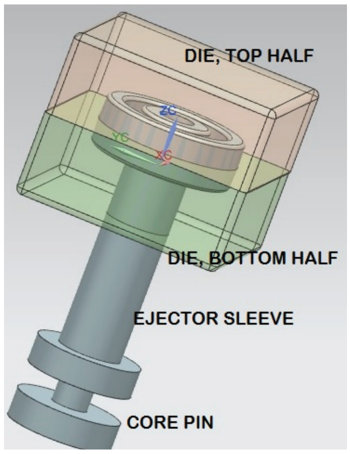

Figure 14. Modeled Assembly of Sleeve Ejection System

Assembly of sleeve ejection system can be observed in a set of images indicated in Figure 15.

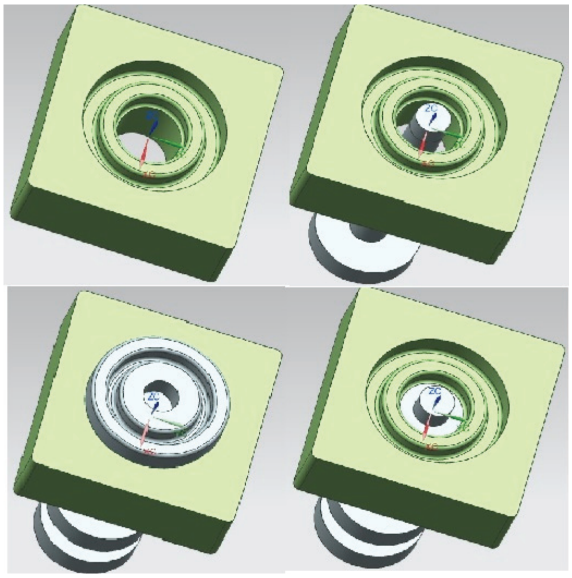

Figure 15. Sequence of Sleeve Ejector Assembly

In Figure 15, fitting of core pin in bottom die insert and fitting of ejector sleeve and placement of component are shown in clockwise sequence. From this figure it is shown that an ejector sleeve in retarded position acts as the surface of the mold. After mold filing and solidification, it advances to push the solidified component away from cavity while the core pin remains stationary at its place. One must understand that the similar profile of bottom half of die is in top half also. But in top half of die the core is inbuilt and ejection of a part from top half is taken care of by sufficient high die opening force.

B. Simulation

By Figure 16, an attempt is made to visualize simulation of sleeve ejection system. The left side image shows initiation of ejection. Top half of the die is removed. The ejector sleeve is at its position and the component is still in bottom half. In the right side image advance of ejector

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sleeve and ejection of the component from die cavity can be observed.

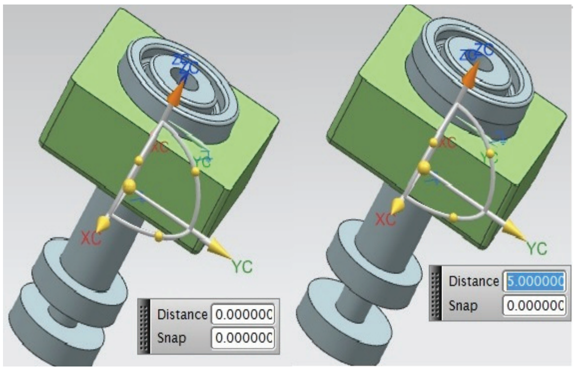

Figure 16. Ejection Simulation up to 5mm Advance of Ejector Sleeve

Travel of ejection sleeve is indicates as 5 mm i.e. component is still 2 mm inside the cavity. Figure 17, shows 10 mm ejector sleeve advance, which is more than sufficient for the required ejection gap of 7 mm and hence the component is ejected completely out of mold cavity.

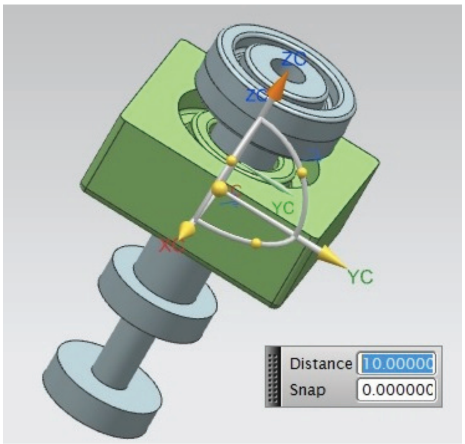

Figure 17. Ejection Simulation up to Sufficient Ejection Gap

V. Conclusions

There are a number of process variables in injection molding, which must be controlled to obtain a defect free plastic component. Years of research in combination with design innovations are overcoming most of them. It is additional responsibility of a tool designer to find innovative solutions for the difficulties coming in his way of tool design. Innovation allows a designer to combine his experience with new learning. Conventionally used ejector pins for ejection purpose is more versatile. But that is not the only solution for each ejection requirement. For smaller and specifically of circular profiled component, sleeve ejection is easy and economical solution. It can be concluded that for large and unsymmetrical components, importance of pin ejection system can't be ignored but at the same time the drawbacks of such systems can be avoided by other innovative ejection techniques. The tool and method discussed in this report is just an approach towards avoiding problems occurred in molded parts due to pin ejection system. A better and more innovative approach can find even more suitable and simple solution for this and many other situations.

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