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On the Quality Enhancement of HDPE Plastic Products by Finite Element Analysis and Experimental Method

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On the Quality Enhancement of HDPE Plastic Products by Finite Element Analysis and Experimental Method

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Abstract. Nowadays; Polymers products are in the way to replace many metal products due to their low cost, light weight, easily production and suitable durability. In plastic injection moulding; the problems of products sticking inside the cavity and the highly importance to keep the products in dimension stability without any distortion during removal needs to be solved. Also the problems of removing a thin wall products form cavity needs optimizing the design of ejection system based on smart modelling and simulation techniques. For these purposes; commercial finite element software (ABAQUS/ CAE) has been adopted for developing a F.E analysis model to estimate the parameters which has major effects on this process. Towards more understanding and to enhance the results, a two cavity mould has been fabricated to produce a thin product, and then tested by suitable injection machine. Simulation results was valuable for early prediction and identification the weak regions where the stresses consternation are in maximum values. Also simulation results were highly desirable in optimizing the design and for reducing time and cost at the design stage, such as experimental characterization. Comparison was made between simulation and experimental results and that was valuable for building new recommendations to the future. It can be also concluded that; the properly designed parts can not only enhance the performance of information technology equipment but also positively impact the disassembly and recycling of the finished product.

Keywords: - Finite Element Analysis; ABAQUS; Simulation; Quality; Plastic injection.

1- Introduction

Polymeric materials typically fall into two different groups: thermoplastics and thermosets. Thermoplastic materials soften when heated and harden when cooled, allowing them to be used in passive cooling iridizations methods. Thermosets cross-link when heated, resulting in a networked structure that has higher rigidity, dimensional stability, and resistance to heat and chemicals. Approved that the product surface must meet design requirements, functionality and manufacturability. The surface structure and quality depend on the mould's manufacturing process. [1].

Estimated that the plastic materials require heat to permanently set, or cure, the plastic. Thermosets materials cannot be re-melted and reformed; thus, their use is limited to "one-time only" applications. This property stems from the chemical reaction that forms a network molecular structure of primary covalent bonds, called cross-linking, during application of heat and/or pressure. In general, some plastic materials offer high thermal stability, rigidity, dimensional stability, resistance to creep, they are lightweight, and have excellent electrical and thermal insulating properties [2-6]. Design for manufacturing is a combination of knowledge based on good understanding of design parameters and manufacturing technology requirements. Combine of optimization formulation with geometrical models will helps to meet the approach toward the goals of solving many of injection moulding

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problems. Virtual prototype can automatically build by modelling process to satisfy the advances feature and multiple objectives [7]. Evaluating these approaches incurs much responsibility on the designer to properly weigh the advantages with the restrictions when choosing a form of digitization. Increased knowledge and even creative tailoring of the available materials should also be considered. [8].
Inverse modelling technique is useful in many times and can used to measure some material parameters. The advantage of this technique is to redirect the model parameters to be very near and fit with experiment conditions. By this approach parameters such as pressure gradients can be and possible to predicted with some extra model simplifications [9]. Approved that the (analytic estimation) is a good analysis solution, in which case the forming product and the mould is divided into components and this method determines cost and time data for the simplified components. Using this method, the engineer must have a deep knowledge in mould design and technology in order to identify the essential features and division borders. The method is very time-consuming, but an expert user with special skills and experience can achieve high level of estimation accuracy. The quality of the estimation depends on the experience and background of the user of the described methods [10].

Temperature profile of (PEHD) can well described through modelling to give a better understanding and determine the effectiveness of conductivity and heat transfer increasing on the mouldings resin. Modelling also is helpful in determination of the optimum level of loading on all the process [11]. Regarding to mold filling, simulations process is often gives satisfied results. However, it is very clear that in physical parameters it's so important to validate the approach of mould flow in large gradients and many phases [12]. In simulation approach, and for a good injection process, a group of conditions should be first determined like thicknesses and part weight. Also a combination of dependent and independent variables as an input values must determine. The required Output results also need to be identified before submitting the job file to analysis and simulation [13].

Simulation of injection moulding process required feasibility verification of mould design and then selection of the effective regions in this design to estimate the optimum results. Injection parameters used in simulation like mould temperature, injection pressure are defend as input data and should not have much differences comparing with actual machine parameters [14].

2. Part Geometry and Modelling Process

Modelling process in this research includes many steps, such as developing model design drawing for the product including all dimensions, shrinkage and tolerances. Figure (1) and Figure (2) illustrate the plastic product used in this work in (2D) and (3D).

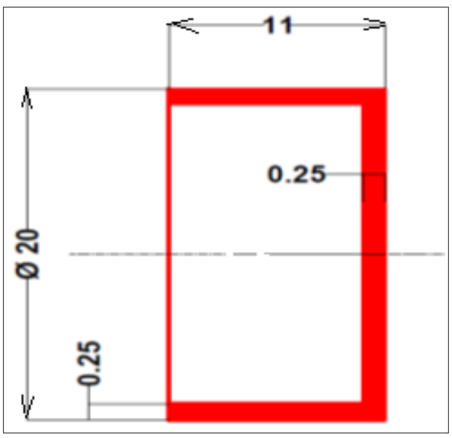


Figure 1. Plastic product with the main dimensions in (2D).

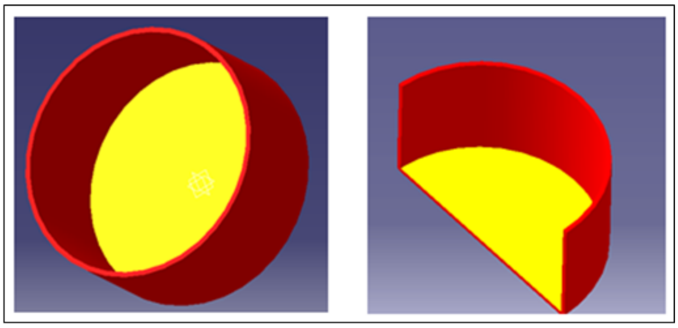


Figure 2. Plastic product in (3D).

Plastic material (PEHD) specifications (shrinkage, density) and the type of tool steel including the mechanical and physical properties must be specified and take in to consideration in the beginning and before any further step. Table (1) summarize these properties.

Table 1. Main properties of (PEHD) and steel.

No.	Properties (HDPE)	Values (PEHD)	Properties (Steel)	Values (Steel)
1	Density	0.96 g/cm^3	Density	7.340 g/cm^3
2	Melt Temperature	130 °C	Yield Stress	375 Mpa
3	moulding Temperature	110 °C	Expansion Coff.	0.00012
4	Deflection Temperature	85 °C	Poisson's Ratio	0.33
5	Tensile Strength	20 MPa	Young's Modulus of Elasticity	200 Gpa
6	Specific Gravity	0.95		

For these purposes, full mould design including all parts with their position and details in assembly drawing depending on the above information has been layout. Figure (3) illustrates a completed assembly design for a two cavity injection mould.

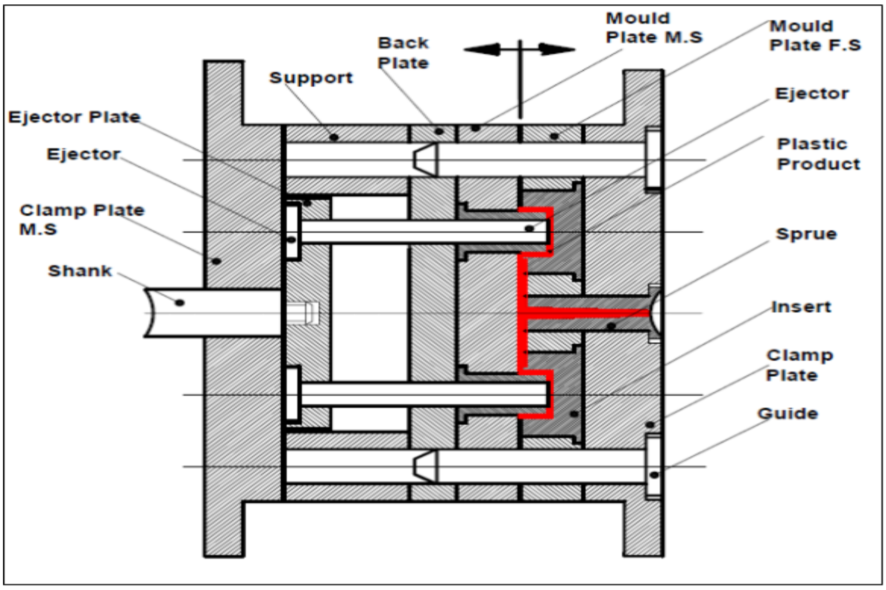
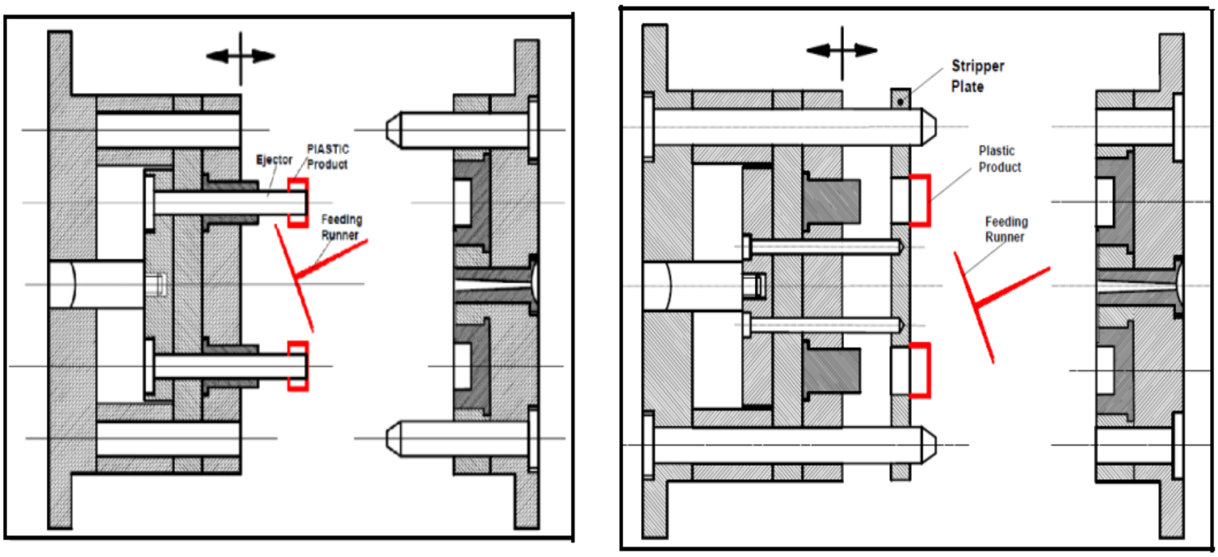


Figure 3. Completed assembly design for a two cavity injection mould.

Some essential requirements and technical data should be available for the mould designer before starting like clamping force, injection pressure, number of cavities, shape and dimensions of runners and gates, ejection forces and material shrinkage.

3. Modelling and Finite Element Simulation Process

The methodology described here is based on and for implementation the main objectives in this research. Two different design methods were used in ejection of the plastic product from the mould cavity. Even though each of these methods are based and follow same standards of mould design, but they have some differences in total ejection forces due to differences in surfaces sticking area of the product. The method of ejection the thin plastic product in the first model is implemented by using ejectors, were the surface area of sticking between ejector and plastic is too much due to the shrinkage property of the plastic. Figure (4 A) illustrate this method of ejection.
Stripper plate is used as ejection system instead of ejector in the second model. The area of contact surfaces between the product and metal is less than the previous one, and the ejection force is uniformly distributed on the outside perimeter of the product. However, this method can prevent any distortion in the product, but in same time there are some considerations should take in account, like material specification and alignment. Figure (4 B) illustrate this method of ejection.



(A) (B)

Figure 4. Illustrate two ejection methods of; (A) by ejector; (B) by stripper.

It's very essential to calculate some injection and ejection parameters before any further step to avoid any problems may happened and cause mould damage due to many variables like; bad contact, time delay or material loss such as flash. Cavity pressure can be calculated by the following equation:

$$P_{max} = F_{max} / A_{max} \qquad (1)$$

Where: (P_{max}.) is cavity pressure, (A_{max}.) is maximum projected area (injection) and (F_{max}.) is cavity force.
It should be note that the clamping force must be > F_{max}.
The force used to eject the plastic part out of mould cavity is called ejection force. This force can be calculated by the following formula:-

$$F = \frac{E*A*\mu*\alpha*\Delta t}{\frac{d}{2t}*[1-\frac{m}{2}]} \qquad (2)$$

Where : (F) is force overcoming resistance force between part and mould (KN), (μ) is coefficient of friction (polymer on steel), (E) is modulus of polymer (N/cm^2), (d) is diameter of circle of circumference equal to the perimeter of the molding (cm), (A) is total surface area of moulding in contact with cavity or core (cm^2), (m) is Poisson's ratio, (t) is part wall thickness in (cm), **(∝)** the coefficient of linear expansion of the polymer (cm/°C) and (Δt) is polymer softening temperature.

There are many advantages of (3D) modelling in this process; it will help to avoid any errors in fabricating and during assembly. The interference between the parts will be obvious and any mistake in dimensions and tolerances can be predicted. Other important function of this modelling is to export this model to other software for analysis and simulation. It can be estimated how can this (3D) model is important by giving a clear perception on the interference between the parts and their position. Figure (5). A. and B. illustrate mould assembly in (3D) model, and a cross section of this (3D.) .

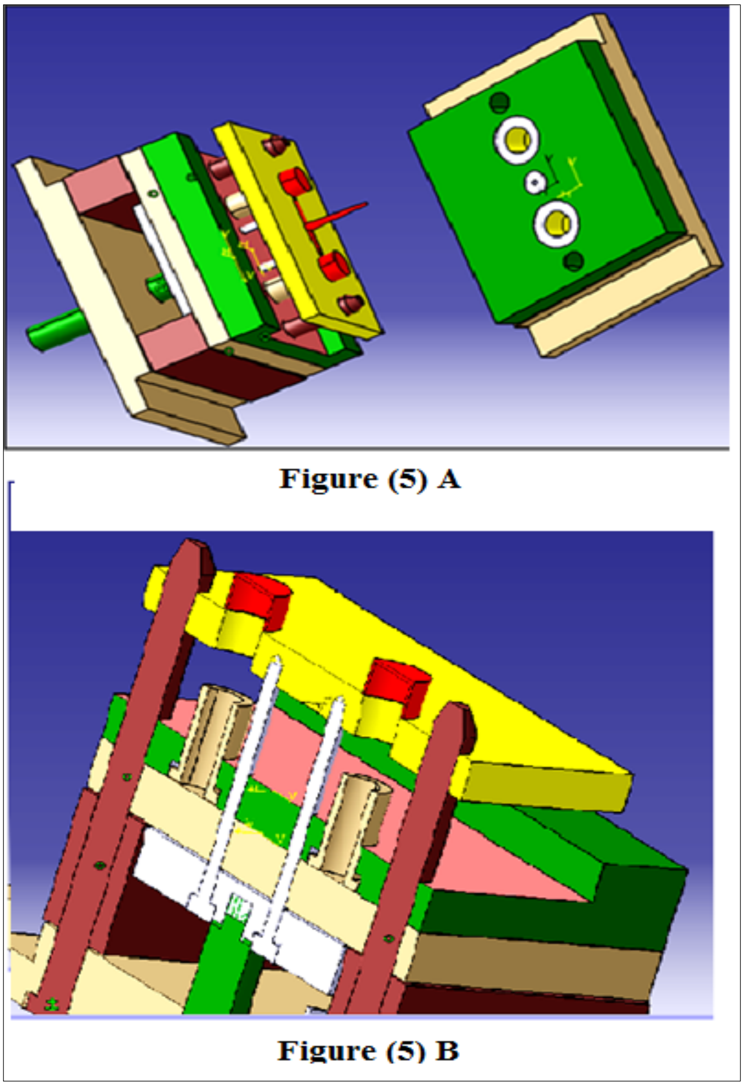


Figure 5. (A) Illustrate mould assembly in (3D) model, (B) Cross section of mould assembly in (3D).

To find the best solution methods for solving the problems of product sticking and to keep the dimension stability of the product; Finite element analysis and simulation process in this current works was made by using two different types of ejection system, and then through comparison it's possible to find out some solutions and recommendations. The procedure of analysis was implemented by (ABAQUS) software using both (2D) and (3D) model.

3.1 Boundary conditions and load

In both 2d and 3d model analysis, the parts like; insert , ejector and stripper are made from steel and consider as rigid body, while the plastic product are consider as deformable body with elastic plastic behaviour.

The boundary conditions include constrain the insert and ejector from motion in any direction in the initial step, while in second step after cavity filling, its include applying load on both ejector and stripper to push out the product out of the insert. The series of sequence process for both two methods are shown in Figure (6). A and B.

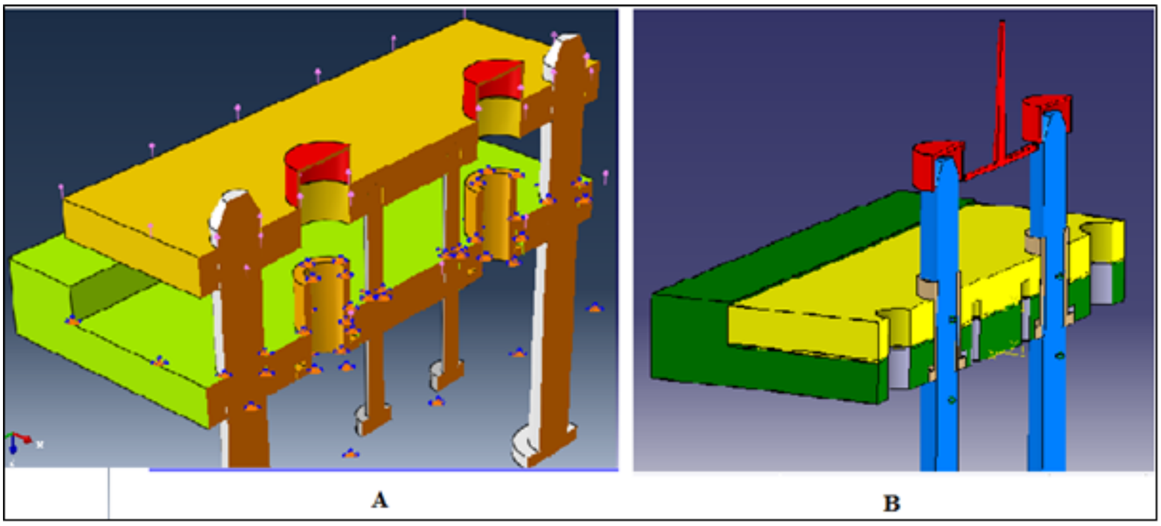


Figure 6. A Ejection model by stripper, B Ejection by ejectors

The boundary conditions on the active parts with applied load and the mesh elements for both types of ejection systems (ejector and stripper plate) are shown in Figure (7) and Figure (8) below.

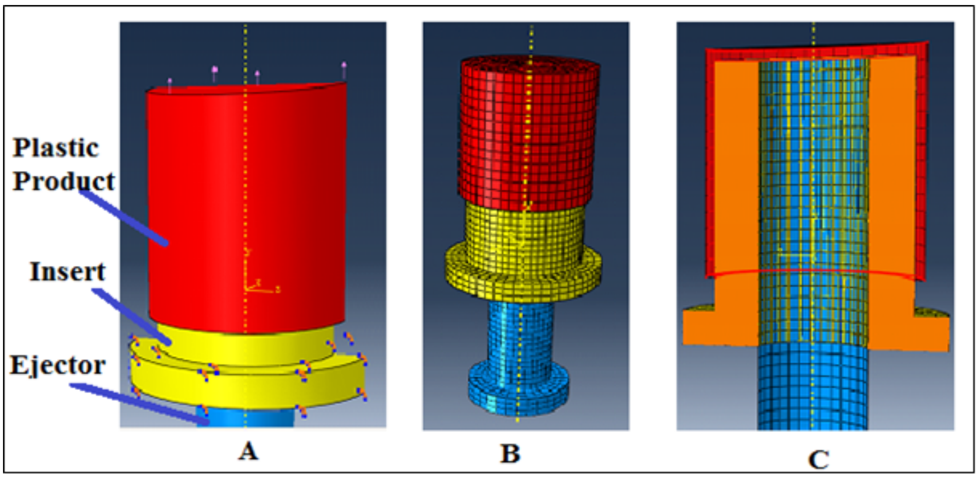


Figure 7. Sequence simulation. A) Boundary condition; B) Parts mesh; C) Cross section.

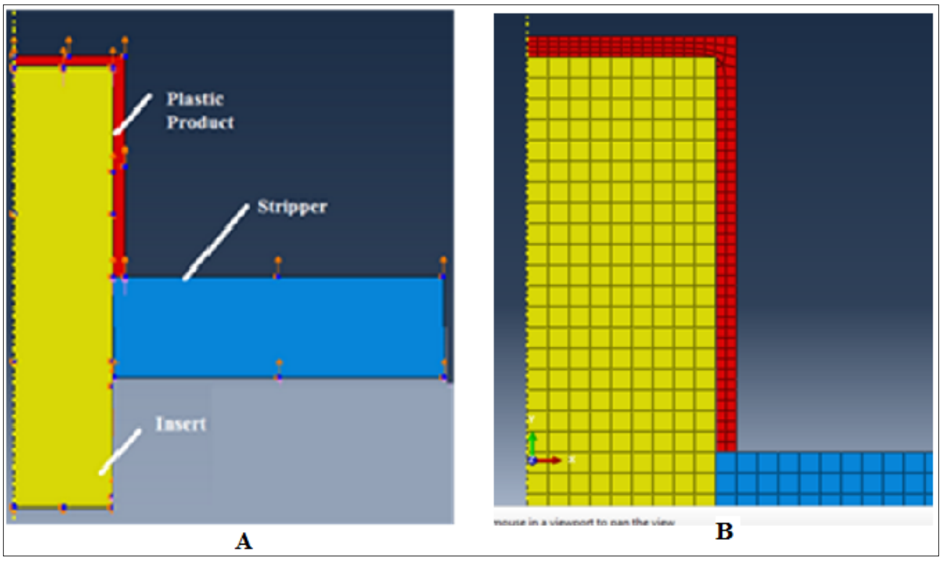


Figure 8. Stripper ejection model. A) A) Boundary condition; B) Parts mesh.

The right procedure in any accurate and visible simulation is the right definition of the interaction between the contact parts and right boundary conditions for each case. Also the type of mesh and mesh accuracy is the main factor which can eliminate the displacement of nodes and the deformation distance during the strain hardening. In this this simulation and due to the nature of part geometries; medial type control mesh with adaptive mesh are used. Even though each of contact parts are subject to heat during the injection process, but the parts in touch with plastic surface will be more strain from the others. For these reasons couple temperature displacement as a boundary condition are used in all cases. Figure (9) is an example for this case during the movement of ejector upward to eject the product.

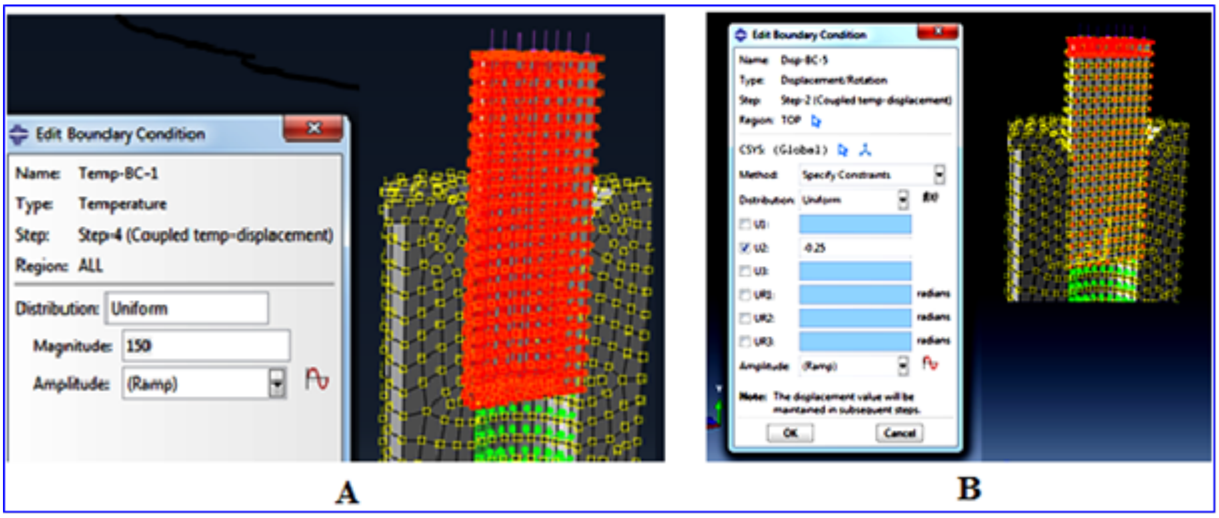


Figure 9. Below

Experimental part included fabrication of a two cavity mould to produce the same part used in the above simulation. The results will used to validate and for comparison with simulation results. Figure (10) show a completed assembly for this mould.

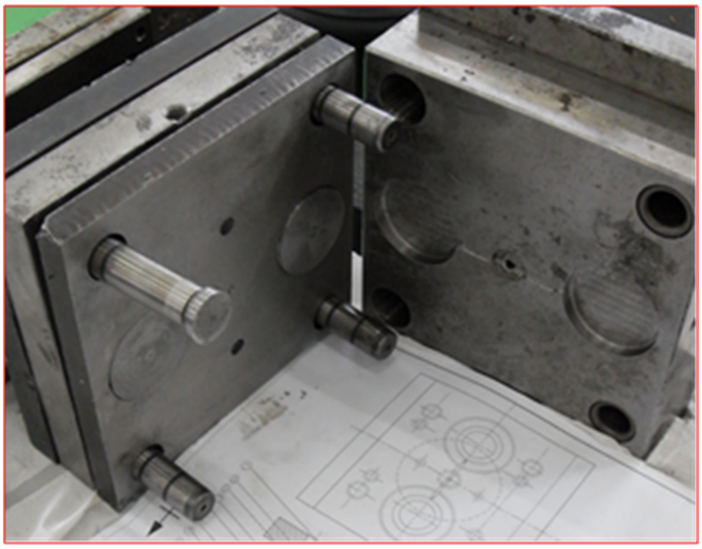


Figure 10. Completed assembly mould.

4- Results and Discussion

In this analyse method; multi steps of design, modelling and simulation are used to clarify the suitable guide for removing or ejecting some common plastic products without damage or distortion.

Regarding to the inverse relation between pressure and projected area, the strain rate and distortion in products can be decreased and eliminated to the minimum by decreasing the area of sticking between the inside surface of product with ejection surface by using stripper system which push the product from perimeter as shown in Figure (11). A and B below

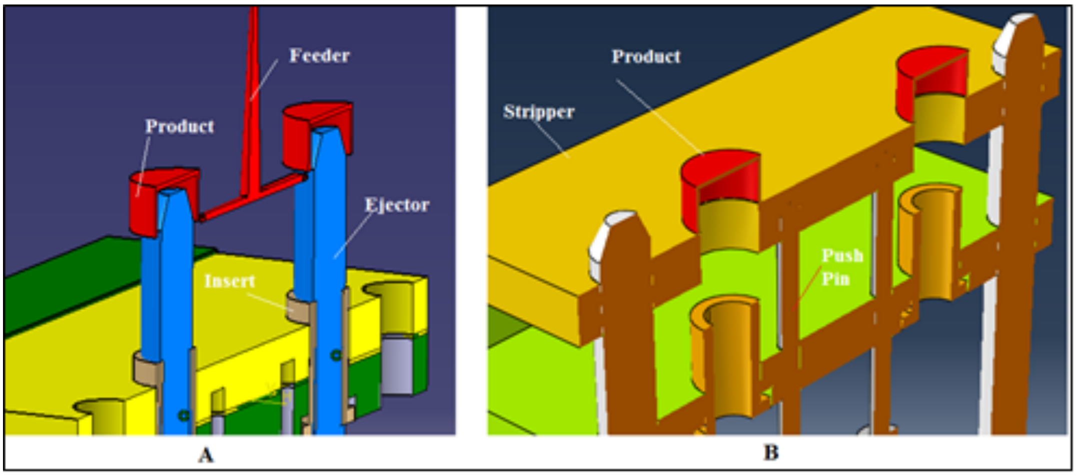


Figure 11. A and B

As a comparison between two methods in terms of generation stresses during ejection process, it has been found that the principles stresses will be in maximum values due to the large contact area and high friction forces between product, ejector and insert, as shown in Figure (12).

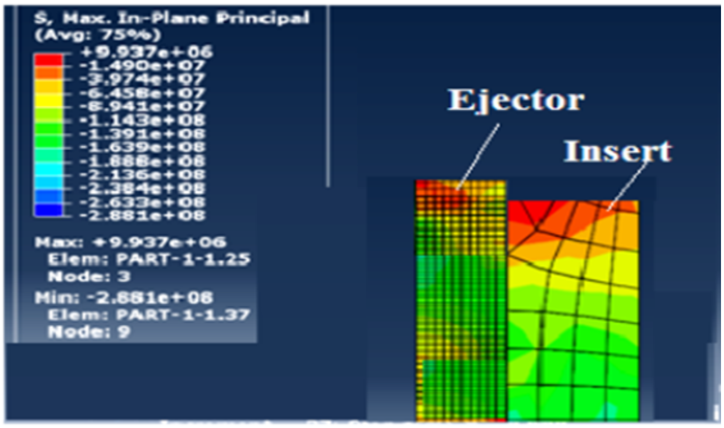


Figure 12. Contour of principle stresses

During ejection the product by stripper plate; simulation results show that the concentration of principles stresses will be concentrate on the outer surface of insert, and especially in contact with the hot molten plastic. On the other side, stresses values were in minimum values around the product surface, and that means less strain and dimension stability. Figure (13) below illustrate the contour of principle stresses for this case.

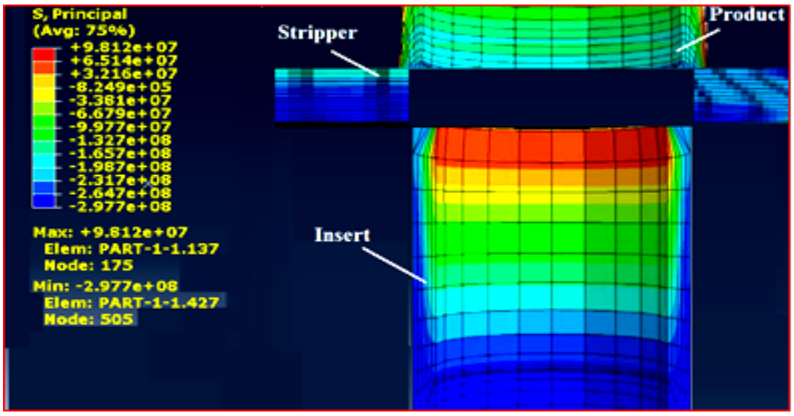


Figure 13. Contour of principle stresses.

Ejection pressures have been estimated during simulation process randomly. As a comparison between the two cases, it has been found that the values was in converge at the starting, and then diverge due to differences in pressure values.

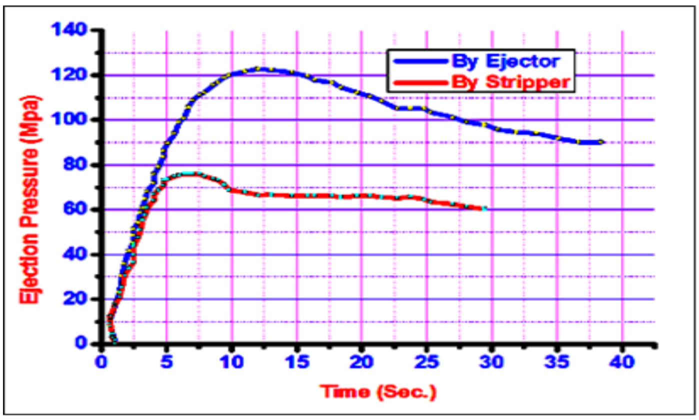


Figure 14. Relationship between ejection pressure and time.

Due to many differences in pressures calibration for each cycle time during experimental test, and due to differences in some boundary conditions for some cases; it's found a non-linearity and little convergence in many graphs. Avrage values for different readings are used for comparison purposes between experimental and simulation results for these three cases as shown in Figure (15).

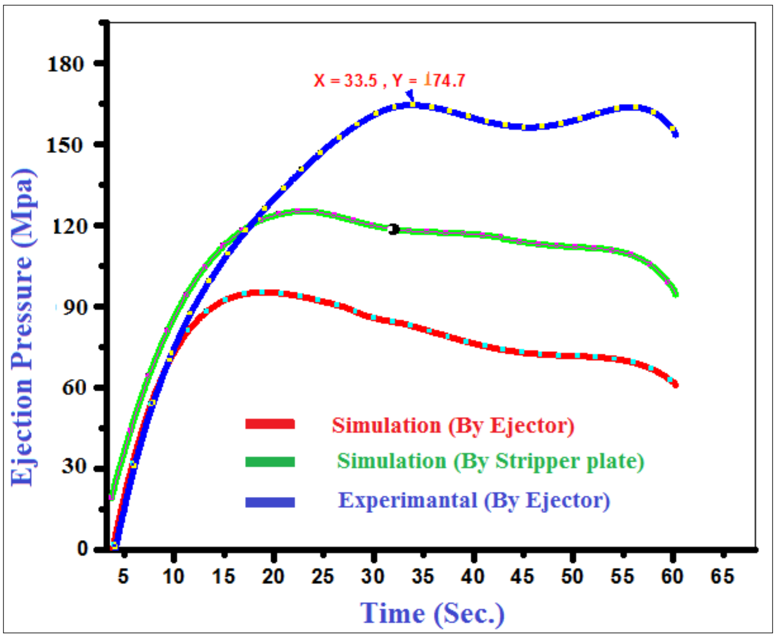


Figure 15. comparison between experimental and simulation results.

5 Conclusions

There are some conclusions are found out from this work and can be summarized as in below:-

1- This work shows how the modelling and F.E simulation can be useful with many facilities such as experiments environments.

2- Behaviour of plastic deformation and the process parameters can predict by using FE model

3- There's a significant effect to the friction between the ejector and inside surface of the product on the dimension accuracy.

4- Plastic strain will increase in the upper surfaces of ejection side and this will cause some uniform deformation in case of smaller thickness.

5- Regarding to the mould filling; simulations can always give satisfied results in many cases, because all of assumptions are based and builds on experimental visualisations.

References

[1] Robert H. Todd, Dell K. Allen and Leo Alting, (2005),*"Manufacturing Processes Reference Guide", Industrial Press*, Inc.,. pgs 240-245

[2] Mario Springolo, (2005),"*New fiber -reinforced polymer box beam", Chap. 2, pgs 12-13 "Overview of fibre-reinforced polymer materials and their manufacture*", Faculty of Engineering and Surveying, University of Southern Queensland , Australia.

[3] Sam, S. T., Dahham, O. S., Gan, P. G., Noimam, N. Z., Kuan, J. Y., & Alakrach, A. M. (2017). Studies on Tensile Properties of Compatibilized and Uncompatibilized Low-Density

Polyethylene/Jackfruit Seed Flour (LDPE/JFSF) Blends at Different JFSF Content. Solid State Phenomena, 264, 120-123

[4] Dahham, O. S., Hamzah, R., Bakar, M. A., Zulkepli, N. N., Ting, S. S., Omar, M. F., Adam, T., Muhamad, K. & Dahham, S.S. (2018). Synthesis and structural studies of an epoxidized natural rubber/titania (ENR-50/TiO2) hybrid under mild acid conditions. Polymer Testing, 65, 10-20.

[5] Dahham, O. S., Hamzah, R., Bakar, M. A., Zulkepli, N. N., Dahham, S. S., & Ting, S. S. (2017). NMR study of ring opening reaction of epoxidized natural rubber in presence of potassium hydroxide/isopropanol solution. Polymer Testing, 59, 55-66.

[6] Dahham, O. S., Noriman, N. Z., Sam, S. T., Ismail, H., Ragunathan, S., Rosniza, H., & Al-Samarrai, M. N. (2016). Properties of Recycled Natural Latex Gloves Filled NBR: Effects of Sawdust and trans Polyoctylene Rubber. Journal of Polymer Materials, 33(4), 647.

[7] Yong Chen, (August 2001),"*Computer-Aided Design for Rapid Tooling: Methods for Mould Design and Design-for-Manufacture*", Academic Faculty Mechanical Engineering, Georgia Institute of Technology, USA.

[8] Jinhuo Wang, (August 2008),"*Predictive Modeling and Experimental measurement off Composite Forming Behaviour*", Ph.D. Dissertation, Chap.1, pg 19, University of Nottingham, U.K.

[9] Torbjorn Odenberger, (June 2005) , "*Compression Moulding of SMC, Visualization and Inverse Modelling*", Department of Applied Physics and Mechanical Engineering Division of Fluid Mechanics, Lulea University of Technology, Sweden.

[10] Balázs Mikó and Ferenc Boór. (2007), “*Enhancing of injection mould quotation accuracy*”. Proc. Estonian Acad. Sci. Eng, 13, 2, 94–104. Egry J. út 1, H-1111 Budapest, Hungary.

[11] Katie Torrey, (2001), "*Influence Of Thermally Conductive Fillers On The Physical Properties Of Waferboard", Department of Chemical Engineering*, Michigan Technological University , USA.

[12] P.T.Odenberger, H.M.Andersson, T.S.Lundstrom. (2004) "*Experimental flow-front visualization in compression moulding of SMC*” Part A 35, p1125-1134.

[13] D. O. Kazmer, S. Westerdale, and D. Hazen, (2008). "*A Comparison of Statistical Process Control (SPC) and On-Line Multivariate Analyses (MVA) for Injection Molding*," International Polymer Processing, 23, 447.

[14] Ashis Gopal Banerjee. (2006). “*Computer Aided Design of Side Actions for Injection Molding of Complex Parts*”. Master Thesis. University of Maryland, College Park in partial fulfillment.