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Application of CAD/CAE Tools in the Design and Analysis of Plastic Injection Mould

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ABSTRACT

Application of CAD/CAE tools in the process of design and analysis of plastic injection mould reduce lead time of the product development and enhance the quality of the product. This paper describes a knowledge-based oriented, parametric, modular and feature-based integrated computer-aided design/computer-aided engineering (CAD/CAE) system for mould design and analysis. The analysis of mould cavity was carried out on different conditions and parameters and the results were tabulated, the results showed that CAD/CAE tools were an excellent approach for analyzing mould defects. With optimum utilization of integrated 3D CAD/CAE system, the injection moulding industries can greatly improve on their process capabilities, predict possible defects before the manufacturing tryout, identify the causes of defects and achieve high quality components at low cost, in a shorter time and greatly enhance the competitiveness of the industry.

1. Introduction

Injection moulding is a manufacturing process that produces parts from thermoplastic and thermosetting plastic. Once a product is designed mould makers prepare mould from metals like steel, aluminium. Material is fed into a heated barrel, mixed & forced into the cavity of a mould then cools and solidifies to takes shape of the cavity [1]. Injection moulding is one of the most important manufacturing processes for making plastic parts available in plastic manufacturing industries. More than one third of thermoplastic materials are processed by injection moulding. With the broader use of plastics parts for consumer products, the injection moulding process (IMP) has been renowned as the most widely used for mass manufacturing process. The technology has always inspired to develop a kind of mould that can produce complicated part more accurately and precisely. Typical moulds are constructed from hardened steel, pre-hardened steel, aluminium,

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and/or beryllium-copper alloy which consists of two primary components, the injection mould (A plate) and the ejector mould (B plate) that are attached to the injection moulding machine [2-4]. CAD/CAE is enabling the creative energies of plastic part and mould designers to be spent in producing better designs in a shorter time period rather than in doing repetitive mould design tasks [5].

The applications of advanced technologies (CAD/CAE) currently become the inevitable trend of industry development. In the manufacturing field, the traditional manufacturing design and production fault to meet the demands of the competitive market conditions [6]. With the rapid development of computer technology and manufacturing technology, there are increasing concerns on how to shorten mould design time and machining production period and to enhance manufacturing quality. Mould technology is also migrating gradually from manual design, relying on manual experience and standard machine processing technology to mould CAD/CAE/CAM (computer-aided design, aided engineering and aided manufacturing) technology. The US has pioneered implementing computer technology on mould industry, realizing mould CAD/CAE/CAM integrated system and achieving purposes of enhancing mould design effectiveness, manufacture quality, and boosting production period [7].

Computer aided Design (CAD) refers to the use of computer technology to assist in the creation, modification, analysis, or optimization of a design. Computer aided Engineering (CAE) is the use of computer software to simulate performance in order to improve product designs or assist in the resolution of engineering problems for a wide range of industries [8]. The CAD/CAE/CAM technology allows product designers and mould makers to work collectively and efficiently. Mould tooling is made quickly by a manufacturing system sharing similar data from a design system in which the product is represented. More importantly, the concurrent approach can be taken for the complete design and manufacturing cycle of a moulding process. This would mean that tooling operations could commence prior to the completion of the design process. In doing so, the lead-time for new product development is shortened, product and development cost reduced, and product quality increased [9].Thermal-structural analyses as well as simulation are carried out on the mould to ensure that the design will not fail under heat effect, fatigue stress, buckling, etc. and to satisfy mechanical properties. Analysis and simulation tools provide support for the design process. They aid designers by providing information about functional behaviour, cost and other concerns pertinent to the design process [10].

The integration of Computer Aided Design (CAD), Computer Aided Engineering (CAE) and Computer Aided Manufacturing (CAM) is now rapidly implemented in mould making technology through the use of computer simulation to analyze the most active areas of the mould design and predict stress - strain, temperature distribution, fatigue damage, defects and possible failure modes, this is to optimize process parameters and die structure provides a very powerful tool, to ensure high quality, reduce material consumption, reduce mould product development cycle and reduce mould manufacturing cost [11-12]. The integrated CAD/CAE system can be used by design engineers to simultaneously check the process and its implementation. The manufacturability, testability, and maintainability can be evaluated, so that the concurrent engineering approach may foresee production problems before putting the design into production [13]. Plastic injection moulding design includes plastic product design, mould design, and injection moulding process design, all of which contribute to the quality of the moulded product as well as production efficiency [14-15]. The rapid advances in computer Software drive manufacturing engineering designers and new technology pursuers to follow these advances and try to benefit as possible from them in the process of manufacturing in order to increase productivity, reduce time and cost, and enhance quality and efficiency [16-17].

2. Methodology

The stages for the design and analysis of plastic injection mould using CAD/CAE tools are:
I. 3D modelling of the part
II. Mould design and Modelling
III. Mould Analysis

2.1 3D Modelling of the Part

Solidworks software was used for generating 3D CAD model of the plastic product. The geometrical specification of the solid model was designed and modelled using sketch and engineering feature tools of the software such as lines, curves surfaces, fillet, Extrude, Extrude cut, round etc. Fig.1. shows the 3D model of the part.

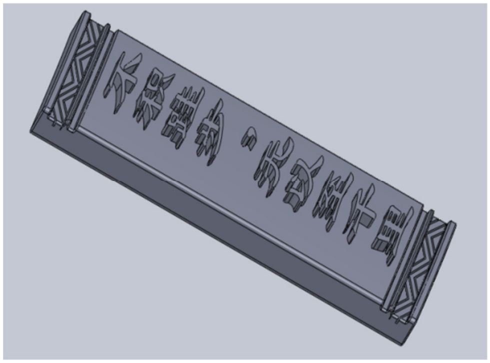

Fig. 1. 3D Plastic part

2.2 Mould Design and Modelling

The 3D injection mould structure was designed based on the injection moulding requirement and modelled using solidworks software based on the specifications of plastic part by exploiting mould tool features of the software such as parting lines, parting surface, geometry plane, sketches, tooling splits, etc. Draft angle of 3o was used for the stress reduction on the tool during ejection process. The Fig. 2 shows the exploded view of the mould.

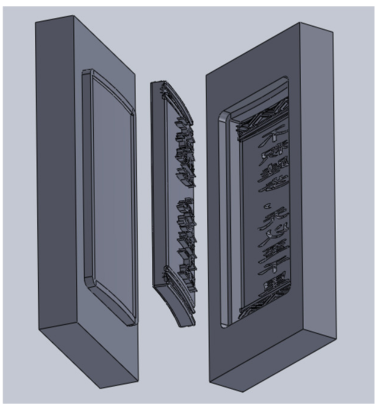

Fig. 2. Mould Exploded View

2.3 Mould Analysis

The data file of the 3D Mould cavity was transferred as parasolid file format to the CAE module for analysis. The mould cavity was subjected to thermal analysis for analyzing the amount of heat induced in the mould during the injection process and structural analysis for analyzing the stresses induced in the mould using ANSYS software.

2.3.1 Mould meshing

The injection mould was meshed in to a finite number of elements and nodes as shown in Fig.3.

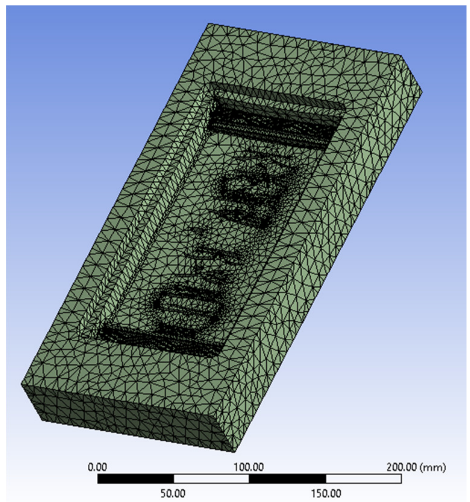

Fig. 3. Mould meshing

2.3.2 Thermal analysis

The mould cavity was subjected to a designated thermal loading at a temperature of 105oC which is the temperature of molten plastics for determining the heat distributions in the mould. Fig.4 shows how the temperature was applied on the mould cavity
Steps; Model > Steady-State Thermal > Loads >Temperature

2.3.3 Structural analysis

In structural analysis, the temperature distribution results were coupled with structural loading of the mould cavity which was rigidly fixed at the designated edges and analyzed to determine deformation, strain and stress due to thermal expansion. The working injection pressure is between 6.9 to 13.8MPa (1000 to 2000psi). A fixed support was applied at the bottom of the mould and pressure of 13.8MPa was applied normal to the surface of the injection mould's cavity as shown in Fig.5.
Steps; Model > Static Structural > Load >Pressure

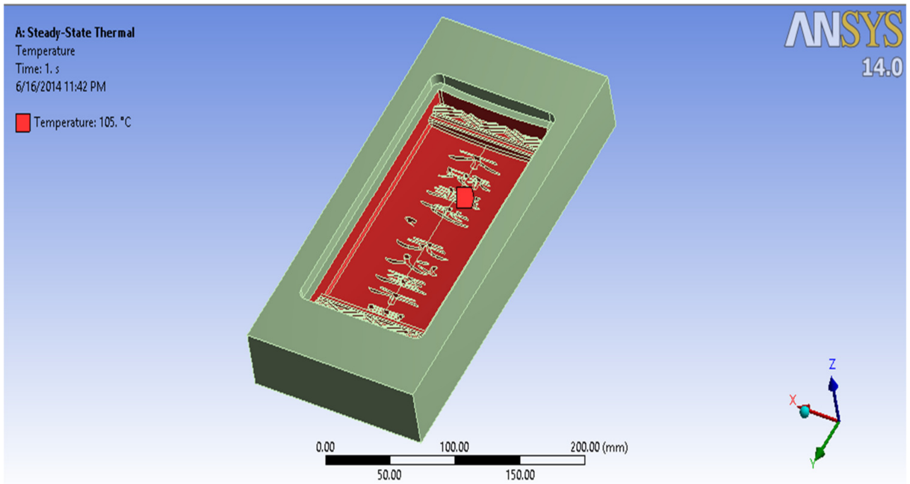

Fig. 4. Temperature was applied on the mould cavity

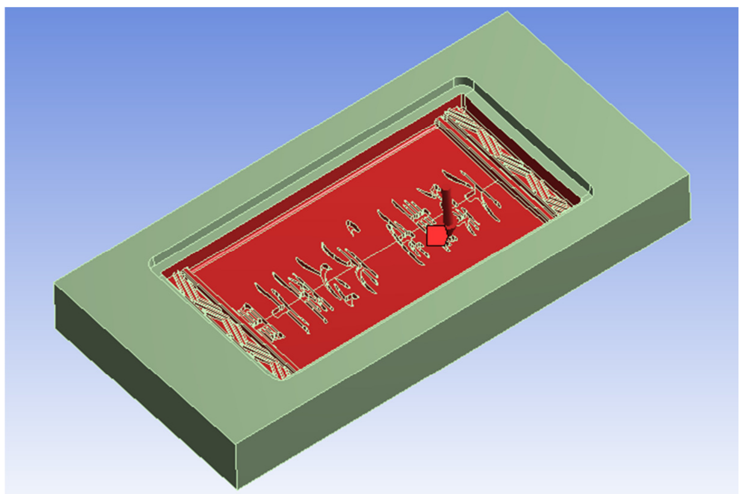

Fig. 5. Pressure applied on the mould cavity

3. Results and Discussion

3.1 Temperature Distribution Results

Figure 6 shows the temperature distributions results at various points of the injection mould.
Minimum value (Blue colour) = 52.841°C
Maximum Value (Red Colour) = 105.42°C

When comparing the results obtained with the melting point of aluminium alloy (671°C), the mould cavity can withstand the effect of thermal loading.

3.2 Mould Cooling rate

Figure 7 depicts the nature of the mould cooling within some time interval and shows how the temperature of the mould cavity drops drastically within short time. The temperature drops from the maximum value (105.42°C) to a minimum value (52.841°C) within 2 minutes.

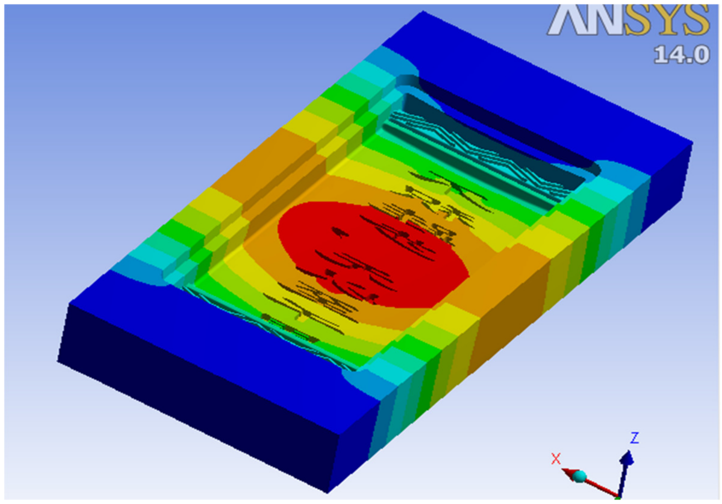

Fig. 6. Temperature distribution of the mould cavity

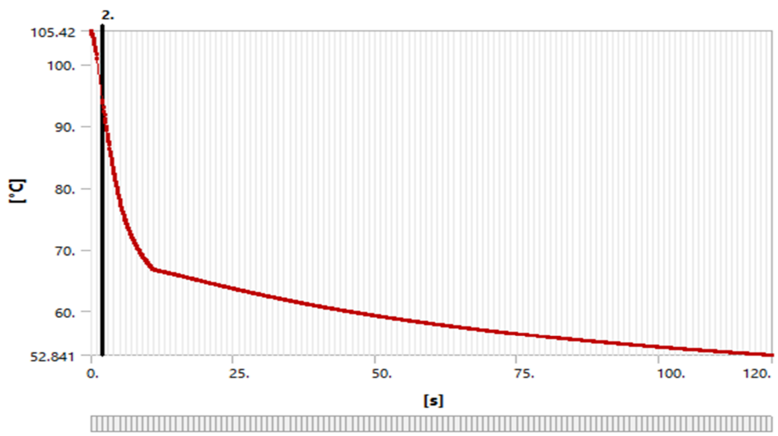

Fig. 7. Temperature (oC) against time (s)

3.2 Deformation Results

The deformation results were obtained and showed in Fig. 8.
Minimum value (Blue colour) = 0mm
Maximum Value (Red Colour) = 0.012282 mm

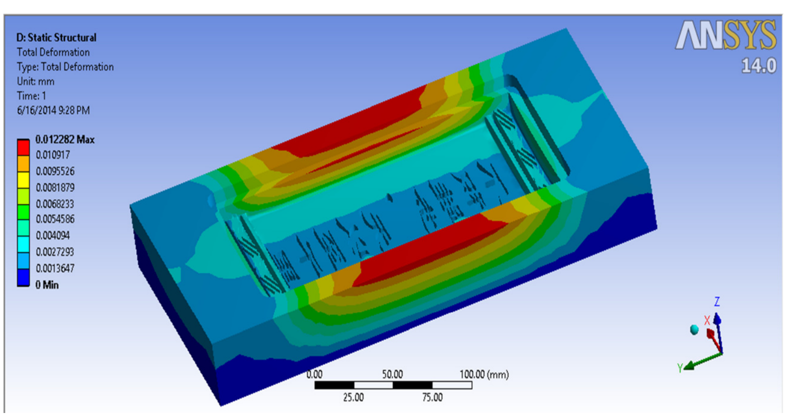

Fig. 8. The deformation of mould cavity

When comparing the results with the mould dimensions (300x150x40mm), the value of the maximum deformation (0.012282mm) is too small for about 0.03% of the mould dimension. Therefore the effect of deformation can be neglected and the cavity has sufficient stiffness and intensity to bear pressure of high-temperature melt there by increasing the accuracy of the plastic product.

3.3 Von-Misses Elastic Strain Results

Figure 9 shows equivalent elastic strain results.
Minimum value (Blue colour) = 6.5735e-007
Maximum Value (Red Colour) = 8.8966e-004

Comparing the results obtained with the dimensions of the injection mould (300x150x40mm), the results are far less than the mould dimensions (i.e. about 0.002% of the mould dimension), therefore the effect of strain can be neglected and the mould has sufficient strength to withstand the effect of thermal and structural loading during the injection process.

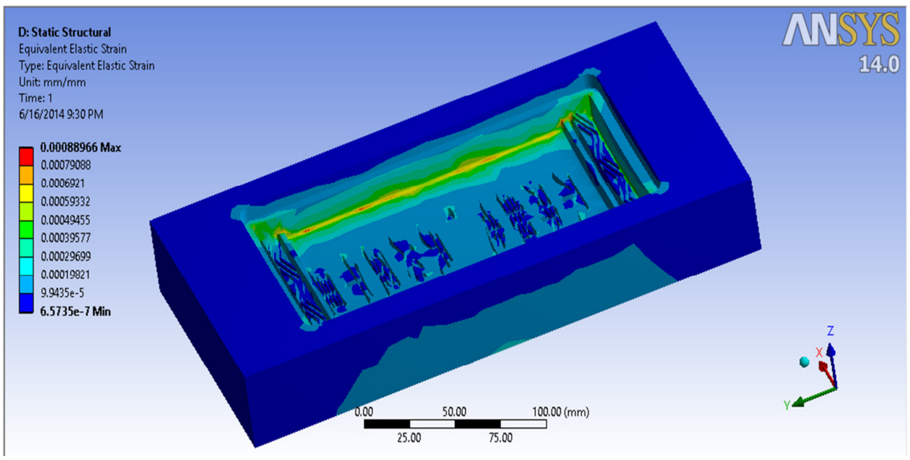

Fig. 9. The equivalent elastic strain of cavity

3.4 Elastic Stress Results

Figure 10 shows elastic stress results.
Minimum value (Blue colour) = 3.1394e-002MPa
Maximum Value (Red Colour) = 61.26MPa

For a safe and reliable design, the values obtained have to be tested using factor of safety. The factor of safety describes the structural capacity of a system beyond the expected loads or actual loads and must be greater than one (i.e. k>1) for a reliable design.

Therefore, the ultimate tensile strength of Aluminium alloy=310MPa

The result obtained for the maximum von-mises elastic stress=61.26MPa

Hence, Factor of Safety (k) = 5.

From the calculated result, the factor of Safety was found to be approximately five which showed that the mould cavity has sufficient strength to withstand the effect of thermal and structural loading.

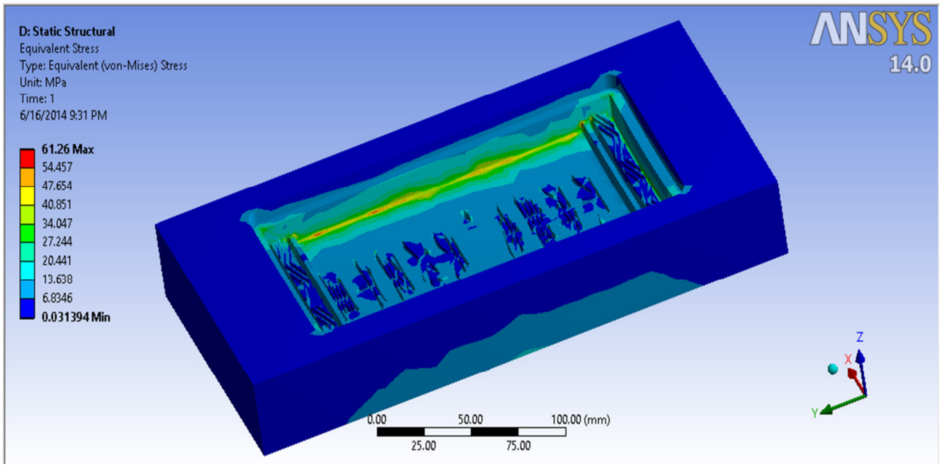

Fig. 10. The equivalent elastic stress of cavity

The Thermal-Structural Analysis results are summarized in Table 1.

Table 1
Analysis Results

S/N	Thermal-structural Analysis	Minimum Value	Maximum Value
1	Temperature distribution (^{o}C)	52.841	105.42
2	Total deformation (mm)	0.00000	0.012282
3	Equivalent elastic strain (mm/mm)	6.5735e-007	8.8966e-004
4	Equivalent von-mises stress (MPa)	0.031394	61.26

4. Conclusion

In this paper, process design and analysis of plastic injection mould by means of CAD/CAE softwares were presented. The results showed that integrated CAD/CAE system was an excellent approach for designing and analyzing mould defects which proves to be a confident software tools. Also the results showed that, with optimum utilization of CAD/CAE integrated technology can improve quality of design, manufacture and Process capabilities of the injection moulding industries. The period of product development and material consumption were also shortened.

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