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Article

A Development of Computer Aided Program for Aluminium Die-Casting Mold Design

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Abstract. In each stage of design, aluminium die-casting mold design is considerate many factors and conditions. The design requires some experiences with trial-and-error platform that causes the problems such as misrun, cold shut, cold shot, penetrations or instability stage during or after molding process. Proposed in this research is about the development of Computer Aided Program to support aluminium die-casting mold design to select and estimate the initial state values under the same standard condition requirements. Before starting a mold design, the C# language is asked to construct the platform that soothes and is insightful or applicably useful in a content database of reference theory, equations and principles including mold parameters. After identifying the proper input conditions of the mold design, the analysis of die casting MAGMASOFT is performed to verify the conditions of the material flow according to the suggested parameters. The simulated results can be considered as the guideline for supporting mold designer where the essential values of mold dimensions and the cold chamber type injection conditions are obtained as easy-to-access graphical images and numerical values. Applying this developed program can help to reduce time spent for mold designing stage with less defects occurred on the obtained cast parts.

Keywords: Computer-aided program, die casting, gating system design, injection condition mold design.

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1. Introduction

Currently the demand for aluminium components to support molding process as "Die Casting" in automotive and other fields or industries have been risen significantly. The casting process is the method that involves high pressure to inject molten material into the mold, the obtained results can provide various styles of cast parts; smooth or textured-surface metal parts, complex features, and more accurate in size and shape comparing to other types of casting process. Due to the increasing demand of aluminium products, it hence leads to the higher demand of mold design process. In manufacturing die-casting work, a "mold" is a tool needed together with production machinery [1]. Feature of mold, injection condition, and quality of the molten metal are considered as the significant variables that have a direct impact on product quality, cost, and production time frame. Mold designing and determining injection condition inaccurately will lead to mistakes in the die-casted work. Aluminium mold designing process is sensitive. There are details that need skills and experiences of the designers to adjust and tune the resulting problems with the finished work in quality and manufacturing process when the mold is practically used.

The key considerations of this proposed research can be classified into two main parts: developing the computer-aided program to support die-casting mold design, and determining the injection condition for cold chamber aluminium die-casting process with several variables in different stages by using C# − language platform. The theoretical knowledge, related formulae, and principles of mold designing are gathered and applied as the theory-referenced database for supporting the developed program.

2. Related Works

2.1. Customer Perceptions on Design

Recently, the main reasons for establishing design and development division are the conversion of customer requirement or market need to a reality-based solution and platform, creating the tangible from the intangible, the creation of new product for supporting smart life, and improving an existing design [2-3]. In the design stage, "*how to meet and satisfy customer's needs*" is one of the main issues where the design engineers should analyze and find ways to reach the appropriate solutions and strategies to support those issues. Sometimes, the users cannot express clearly about what they really want via words or freehand sketching objects with only a pencil and blank paper, as the results, the specific or technical terms of the product or design they would like to create or purchase are hidden and cannot be extracted out properly [4]. After extracting "*target customers*" and "*what they really want*", the conceptual design platform is introduced, and it might be remodified according to the conditions of manufacturing processes. Over the last few years, trial-and-error activity has been considered and applied in small and medium enterprises (SMEs). SMEs are defined as independent firms which employ less than a given number of employees, and they play as a major role in most economies, particularly in developing countries [5].

Although, SMEs are the backbone of economy, crucial for economic growth and prosperity, and with a high capacity for innovation, with limited in number of workers/staffs, some redundant tasks and manual mode activities are presented frequently. The drawbacks are shown through some wastes and defects found during performing tasks from one station to another. The experienced people, sometimes, they simply think that there are no accidents during working since they have been performing same tasks every day, and the main point is "they know better than anyone". That claim is true in the sense that one can learn from everything, and extract knowledge from every possible entity. However, the human errors are found in the workplace; tardiness that is the habit of being late or delaying arrival, fatigue that happens when working same style of tasks continuously, and boredom of the long working hours. The eight-hour workday is an ineffective approach [6-7].

Moreover, performing task manually is time-consuming process and there are no quantitative prediction of process conditions. This would be better to apply digital platform with full- or semi- automatic modes for supporting and involving in the whole process of manufacturing field. Manufacturing engineering, or the manufacturing process, are the steps through which raw materials are transformed into a final product. The manufacturing process begins with the product design, and materials specification from which the product is made [8].

Recently, some scientific methods and techniques are required and progressed dramatically where virtual reality is the key consideration for all platforms [9]. The software part should be presented in both 3D animation and reported in 2D document forms for easily transferring data from one division to another. Virtual reality and graphical simulation platforms have been introduced for supporting the ways to transform imaginary ideas for customers to be a digital or 3D form easily and quickly [10]. All programs or platform-specific source sets depend on the common source set by default, and the default parameters should be assigned and suggested from the group of skilled or experienced people.

2.2. Mold Design Issues and Simulation

Molding defects are often caused by some process problems: *flow lines* (i.e., a wavy pattern with small different colors is presented around the narrower areas of the obtained part); *burn marks*; *warping; vacuum voids* or *air pockets*; *sink marks*; *weld lines*; and *jetting* [1, 11].

In order to minimize the risk of product defects after molding process, a visual-based flowing platform as mold filling simulation has been introduced in various directions [12-14].

Mold filling simulation has been introduced as a vital channel for supporting mold designers to create the pattern and components of the mold with less unexpected issues found during operation; the main defects are originated from mold filling activity. In practice, the accuracy of the obtained part is considered and depended on material properties, boundary conditions, and modelling of various phenomena occurring during mold filling. Recently, the ways to eliminate chances to face the surface tension and melt flow problems have been focused on the fluid flow simulation with consideration of surface tension [12-13].

However, the applications of these methods to casting simulation are not easy because time spent for CPU processing is quite long where the sufficient or proper mesh resolution is not allowed at thin sections. Some researchers have tried to develop a direct method where the curvature is topologically calculated from the melt surface using non-dimensional distance from the element surface to the melt front [13-14]. This direction can perform and handle the case in various categories; even when the cavity thickness is divided by only one element. As the result, this would be a bright direction to obtain proper condition for material flowing platform. The strength of this method is shown as the situation where the melt velocity can still be decreased at thin sections even in the case of high pressure die casting (HPDC); the effect of surface tension becomes small when the melt speed is high.

Simulation gives different results when using different methods for the same simulation. *Autodesk Moldflow Simulation* software provides two different facilities for creating mold with the simulation of injection molding process. Mold can be created inside the Moldflow platform or it can be imported as CAD file from other sources [15]. Studying about difference in the simulation results such as mold temperature, part temperature, deflection in different direction, time for the simulation, and coolant temperature for these two different methods has been introduced.

For the Euler method, this was adopted to treat the liquid phase, columnar grain phase, and equiaxed grain phase as continuous phases. Moreover, the mass, momentum, energy, species transport equations of each phase, and the equiaxed grain density equation were determined simultaneously. For feeding a steel strip into a continuous casting (CC) mold, this has been introduced as an effective method to improve the internal quality of CC slabs [16]. In order to investigate the solidification structure evolution during the cold strip feeding process, an alloy experiment and three-phase mixed columnar-equiaxed solidification modeling were applied.

However, it would be better to understand and study more about the design of mold and die where the proper conditions with various material types and characteristics have been taken into considerations [17-26].

2.3. Proper Conditions for Mold and Die Design

Recently, some researchers have tried to find the optimal solutions for supporting mold and die applications where material considerations have been considered as the key areas. For minimizing errors found during pouring or casting process, some techniques relating to visualization and analysis of material flow through gating systems were introduced [17-24].

2.3.1. Mold design issues

The concept of a transient 2D axisymmetric mathematical model that couples the pulse electromagnetic field with fluid flow and solidification was established by using the *COMSOL Multiphysics* software [21]. According to the measured pulse currents under different electromagnetic parameters, the model was firstly validated, and then the solidification processes of direct-chill (DC) casting in the absence and presence of pulse magnetic field (PMF) were simulated and discussed where the variations in fluid flow, heat transfer, and solidification characteristics at different locations of the melt were included.

The benefits obtained from this research can be considered into three main categories:

- The forced convection induced by PMF can significantly accelerate the melt flow and heat extraction.
- For billets with different magnesium alloy systems and sizes, a fined and uniform solidified structures can be obtained by adjusting the current intensity and electromagnetic frequency in pulse electromagnetic DC casting.
- The effects of pulse electromagnetic parameters (current intensity, electromagnetic frequency, and duty cycle) on Lorentz force, flow field, temperature field, and solidification during DC casting of AZ80 magnesium alloy can be considered and studied systematically.

2.3.2. A systematic computer-aided approach to cooling system optimal design in plastic injection molding

Since the cooling system design is one of the important considerations for supporting plastic injection molding; it significantly affects the fast productivity while maintaining high quality of the final products. A systematic computer-aided approach is developed to achieve the cooling system optimal design where the various aspects of the optimization process for cooling system design are investigated. For supporting this platform, the cooling analysis using boundary element method (BEM), a perturbation-based approach to design sensitivity analysis, optimization problem formulation, and a novel hybrid optimizer based on Davidon–Fletcher–Powell (DFP) method and simulated annealing (SA) are considered [22].

2.3.3. A fast and reliable thermal cure profile design method

Recently, the mold temperature uniformity has a crucial effect on the quality of composite part manufactured by the autoclave curing process, especially for large size mold [23]. This has been a critical and challenging issue to a mold design stage where the appropriate thermal cure profile can improve the temperature uniformity and reduce the manufacturing cost.

In practice, the typical autoclave cure cycle is mentioned as a two-step process; vacuum and pressure are firstly applied while the temperature is ramped up to an intermediate level and held there for a short period of time. However, the heat reduces the resin viscosity; allowing it to flow and making it easier for trapped air and volatiles to escape. The volatility can be considered and described as how readily a substance vaporizes. At the assigned molding condition where the temperature and pressure are the key points, a substance with high volatility is more likely to exist as a vapor, while a substance with low volatility is more likely to be a liquid or solid [25].

The application of "*a computational fluid dynamic (CFD)-based autoclave simulation model*" is firstly established for supporting a large-framed mold and easily checking or proving the validity or accuracy of fluid flow (i.e., three dimensional model from the activity to visualize how the fluid would flow). This platform offers reliable evaluation about the thermal behavior and heat transfer coefficient (HTC) of the curing mold. After that, "*a novel method*" is introduced by applying unit volume element-based simulation to represent the highest and the lowest temperature histories of the mold top surface as accurately as the CFD-based simulation while minimizing computation time significantly.

At the final stage, the thermal cure profile optimization is performed by combining the genetic algorithm (GA) and the unit volume element method for minimizing the temperature gradient and cure time simultaneously. Applying this platform can obtain some benefits as:

- The temperature uniformity governs the final part quality and the cure time governs manufacturing cost.
- The well-designed thermal cure profile can improve the autoclave curing process.
- This design can be applied to various large size molds for manufacturing large composite parts.

2.3.4. Weld line reduction issue

Weld line reduction is one of the major concerns in plastic injection molding (PIM) that results in high surface appearance and high strength of a plastic product [24]. In order to eliminate this issue, the rapid heat cycle molding (RHCM) is considered for attracting attention as an innovative PIM technology; the mold temperature profile is stated as a crucial role in weld line reduction. High productivity plus high surface appearance are required in the PIM, and the trade-off between them will be observed. For achieving weld line reduction and high productivity simultaneously, the way to adjust both mold temperature profile and other process parameters in RHCM is the main point.

2.4. High-pressure Die Casting Dies

For assisting the conventional subtractive manufacturing processes, high-pressure die casting dies have been produced. A massive design of the die usually ensures high stability during the casting process. However, at the same time, it leads to low flexibility in casting production and high material costs [26-28].

High-Pressure Die Casting (HPDC) is considered as a near-net shape manufacturing method for the non-ferrous materials casting process, and it is widely used in the automotive industry and mass-production platform [26]. In the HPDC method, mold (TM) and casting temperature (TC), first- (V1) and second- (V2) phase injection velocity, injection pressure (P3), mold and casting material, and mold design and vacuum application are all important parameters for producing high-quality products. Since they directly affect the mechanical and metallurgical properties and micro–macroporosity of the product parts.

The factors used in the research are considered as the set of type of heat treatment and cooling rate of each step. In the process, the microstructural analysis was conducted to observe the mechanism of mechanical property that is changing. The combination of heat treatment type and cooling rate enabled the control of ductility and strength properties in AA365 is taken in to consideration.

The effects of thermal (i.e., mold and casting temperature), injection parameters and dynamic (i.e., pressure, velocity and vacuum application), injection parameters on the mechanical properties, and porosity of the samples were studied where A383 was selected as the casting material and DIN 1.2344 was applied as the hot work tool steel.

In the experiments, the mold cavity was shaped according to the tensile test specimen. The activities were repeated under 64 different conditions by using different dynamic and thermal parameters where the vacuum application was drawn in the mold cavity. The samples obtained from the experiments were subjected to tensile tests to determine their mechanical properties. For measuring and calculating the porosity rates, a gas pycnometer was used.

All the tests were simulated by using FLOW-3D software according to the experimental conditions. The suggested parameters from the simulation were presented as these following statements:

- The most useful thermal parameters obtained from the experimental study were found to be 1063 K for casting temperature and 493 K for mold temperature, while the optimum dynamic parameter values were determined to be 1.7 m/s injection velocity and 10–20

MPa injection pressure for vacuum application drawn in the mold cavity.

- The mechanical properties of AA365, an Al–Si–Mn–Mg alloy used in high-pressure die-casting of automotive parts, can be optimized for a proper application using different heat treatments [27]. During a die-casting process including heat treatment, aluminum alloy cast components experience considerable changes in their mechanical properties due to the non-uniform cooling phenomena.
- The mechanical properties of AA365 with different cooling rates during T4, T5, and T6 heat treatments were investigated and analyzed by a statistical method using a design of experiments protocol to see which factor is the most significant for mechanical properties.
- Moreover, the basic approach has been introduced to reduce the conventional subtractive production process of a die casting die in favor of a flexible, modular design, where only a few contour elements of the die have to be replaced for achieving different castings [28].
- In order to support the design principle with easy-to-access platform, the basic thermal and structural properties of a lightweight design in die casting were analyzed. The finite element calculations carried out showed that the modular lightweight die casting consumes less energy greatly for preheating and during operation.

However, due to stiffness and material reductions, the calculated deformations and stresses in the die are considerably higher during the casting process. Although the initial calculation results can provide reasonable direction to obtain and promise clean and clear quality of the output, further knowledge and alternative design model should be gained and developed in order to ensure the successiveness of modular lightweight die casting dies.

3. Research Concept

The two main considerations of this proposed approach which are *developing the computer aided program*, and *determining the injection condition*, will be presented in the sub-sections below.

3.1. Die Casting Mold Design System

The benefits obtained from the related researches have been applied as the guidelines for creating the die casting design platforms [29-42]. The procedures in designing aluminum mold are the followings.

3.1.1. Determining preliminary data in the design stage

Determining preliminary data is related to the product and mold manufacturing process that includes part data, machine data, mold material type, and aluminium alloy type for supporting the input data in designing and calculating several variables in different stages of design.

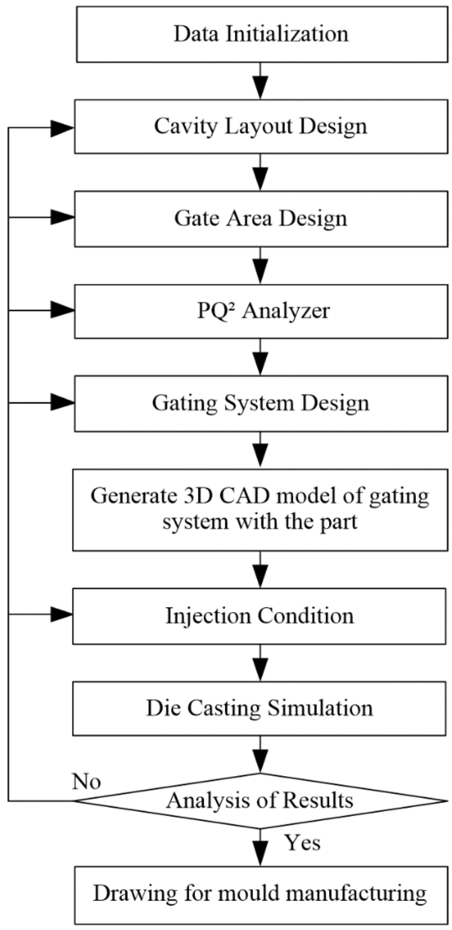

Fig. 1. Aluminium injection mold designing procedure.

3.1.2. Cavity layout design

This process is about selecting the proper conditions of the components inside the mold where the key points are *determining numbers of cavities*, *selecting the position for feeding system*, and *identifying the layout pattern for the cavities within the mold*, are considered and addressed according to the capability of the injection machine mentioned in Kumar, Madan, & Gupta (2013) [43].

The number of cavities in the mold is determined by the calculation from clamping force; N_{cf} , and maximum shot volume; N_{sv} , according to the first equation.

$$\text{No. of cavities } = \text{Min}\,(N_{cf} \text{ and } N_{sv}) \tag{1}$$

3.1.3. Gate area design

The key areas of the gate design are considered as the following statements.

1) Designing the flow pattern design to control the ingate and select types of gate runner as shown in Fig. 2.

2) Calculating the filling time by applying Eq. (2).

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$$t = K\left(\frac{T_i - T_f + SZ}{T_f - T_d}\right)W \quad (2)$$

where K is empirical constant, T_i is injection temperature, T_f is liquid temperature, T_d is die temperature, S is percent solids, and Z is Units conversion factor as refer to Pokorny, & Thukkaram (1984) [44]. In this study, the key term of " T_f " is considered as "aluminium melting temperature" (i.e., raw material that is melt and poured into the mold) where the concept of "solidification"; the process of transformation of a liquid to a solid, is applied. At the end of the stage, the cast part (or a final desired product) is obtained.

3) Determining the size of overflow by considering the part's thickness and filling time in comparison to the ratio of overflow volume [45].

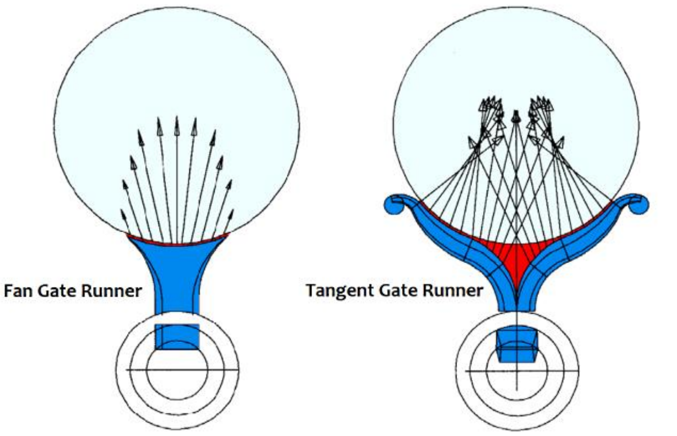

Fig. 2. Fan Gate runner and tangent gate structure [46].

4) Assigning gate velocity; V_g which depends on the work's thickness and materials used in die-cast as refer to Pokorny & Thukkaram (1984) [44].

5) Calculating the gate area; A_g

$$A_{ag} = \frac{V_c}{t \times V_g} \quad (3)$$

where V_c is cast volume.

$$A_g = \frac{A_{ag}}{\cos(\theta)} \quad (4)$$

where A_{ag} is apparent gate area, and θ is Flow angle

6) Assigning the gate depth; D and gate width; W

$$D = \frac{A_g}{W} \quad (5)$$

The gate velocity is checked by using an empirical formula recommended by NADCA (2006) [47] which is mentioned in Eq. (6). Checking the size of in-gate for the proper flow by atomization check is required; when the results obtained from Eq. (6) is less than 1 (> 1), this means "PASS".

$$\frac{\left[\frac{D \times W}{D + W}\right] \times \rho \times V_g^{1.71}}{J} \geq 1 \quad (6)$$

where ρ is density of material, and J is atomized flow factor.

3.1.4. PQ² Analysis

The technique of PQ² is used to investigate the compatibility of the mold and die casting machine by using the PQ² diagram to consider the power needed for molding and the selected injection power accordingly as mentioned in Henry (2006) [48]. The correlation is shown in Fig. 3.

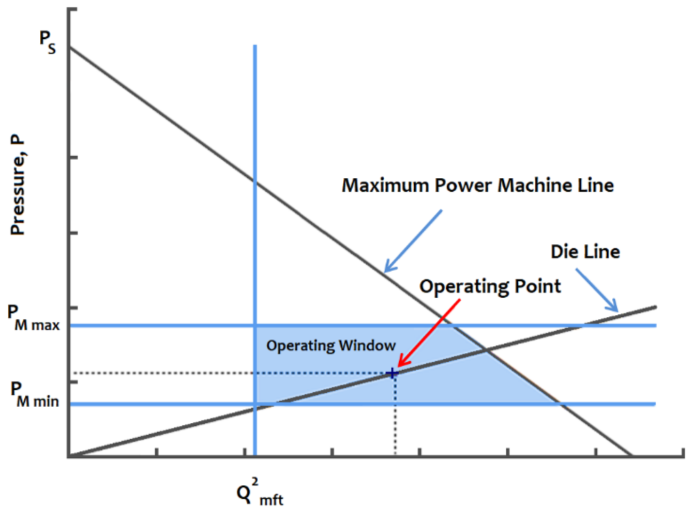

Fig. 3. PQ² Diagram [49].

3.1.5. Gating system design

Designing the gating system is the way to control the flow of the molten metal within the cavity involving biscuit, runner, gate runner, in-gate, overflow, and air vent (Fig. 4). The design needs to match with the machine characteristics and properties. Moreover, the design platform should be contemplated or considered with continued attention about the quality of die-casting work.

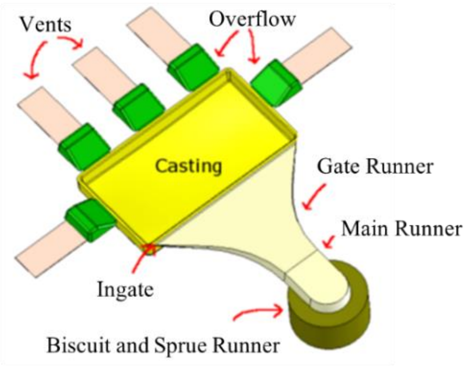

Fig. 4. Components of the gate system for the aluminum casting mold [50].

The procedures of design stage required for gate systems and the calculation for different sizes and dimensions are described in the following statements [44].

1) For calculating dimensions and sizes of in-gate and gate runner, the calculation is separated by considering the types of gates entered. The assigned flowing gate is the gate runner that connects to the main runner; allowing the molten metal to be flowed and filled from the gate runner to the main cavity.

2) For calculating the design of the size of runner, this is about the assigned direction for molten metal to flow from the biscuit that will eventually enters the in-gate by the 2 ends. This 2-end platform is attached with the gate runner: outlet end, and inlet end that is attached with the sprue. The most common and popular shape of cross-section is trapezoid. In designing, the distance should be the shortest in order to prevent the temperature of liquid-state metal to decrease while the filling process.

3) Calculating and designing of the biscuit and sprue runner.

4) In overflow designing platform, the overflow ratio compared to the die-casted part's thickness and the filling time are taken into account. The amount and size of overflow can be calculated by Eq. (7), where O_n is number of overflows, V_o is total volume of overflow, V_u is volume of single overflow unit.

$$O_n = \frac{V_o}{V_u} \tag{7}$$

5) For the stage of selecting type of venting; the definition of venting should be well defined. Since the venting is considered as the supporter to ventilate the air inside mold cavity while filling the liquid-state metal. The oxide is the key issue where it is mixed with water and gas. The vent is about the small opening in the mold to facilitate escape of air and gases. Moreover, the air trapped inside can be easily released when the proper design with right location of the vent is provided. Inappropriate air vent design always induced porosities in thin and complex shape of high pressure die-casting (HPDC) products. Moreover, for HPDC, the chill vents are used to allow residual air and gases to exhaust out from the mold cavity. Selecting the proper type of venting style (between air vent and chill vent) can deliver clean and clear surface of the cast part.

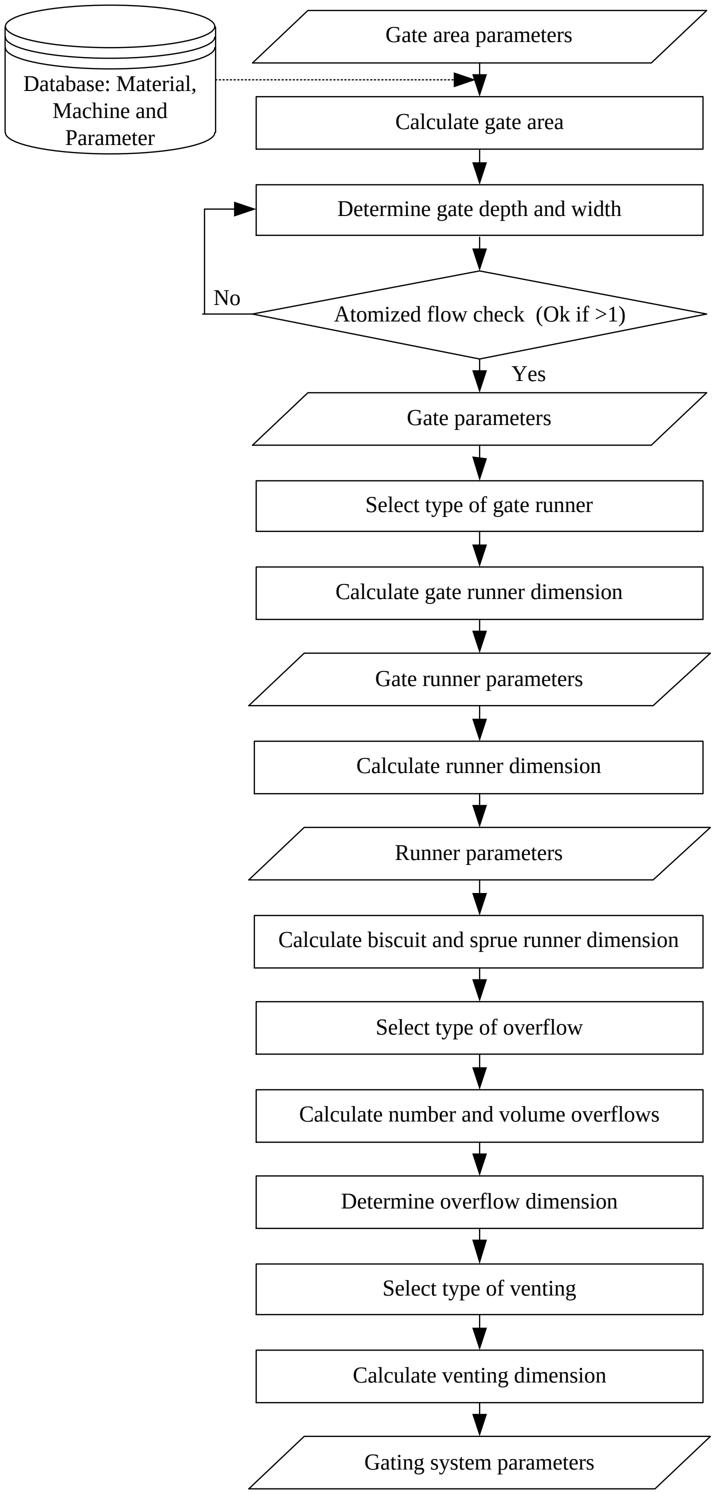

Fig. 5. Diagram showing the procedures of designing the gate system.

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3.2. Determining the Injection Condition

After constructing 3D model for the gate system of the die-casting part, the step of procedure is performed to determine the condition for injection which will utilise the assigned preliminary data and the parameters of the gate system, along with the information about the size of the die-casted work and the gate system retrieved from the 3D model to calculate and find the parameters value for injection. The system of injection platform can be classified into 3 main phases: *slow-shot phase*, *die filling phase*, and *pressurization phase*. The key point of this study is about the condition of liquid-state metal from the injector to the mold. Presented in Eq. (8) to Eq. (13) are the tools applied for finding the proper values of different parameters.

1) Slow shot velocity; V_{ss}

$$V_{ss} = C\left(\frac{100\% - F_i}{100\%}\right)\sqrt{D_p} \quad (8)$$

where C is curve fitted ($0.579\ m^{0.5}/s$), D_p is plunger diameter, and F_i is initial fill percentage.

$$F_i = \left(\frac{V_{ts}}{A_p \times L_s}\right) \times 100\% \quad (9)$$

where V_{ts} is total shot volume, L_S is total sleeve length, is A_p project area of plunger.

2) Slow/Fast transition point, S

$$S = \frac{V_c}{A_p} + c \quad (10)$$

where V_c is volume of part and overflow, c is clearance of transition point (c = 25 – 50 mm).

3) Fill time, t_f

$$t_f = \frac{V_c}{Q_f} \quad (11)$$

where Q_f Flow Rate ($Q_f = A_g \times V_g$).

4) Fast shot velocity; V_{FS}

$$V_{FS} = \frac{V_c}{t_f \times A_p} \quad (12)$$

where t_f is fill time, V_c is volume of part, and A_p is project area of Plunger.

5) Intensification pressure; P_I

$$P_I = P_h \times R_i \quad (13)$$

where P_h is Max. Hydraulic pressure, R_i is Intensification Ratio.

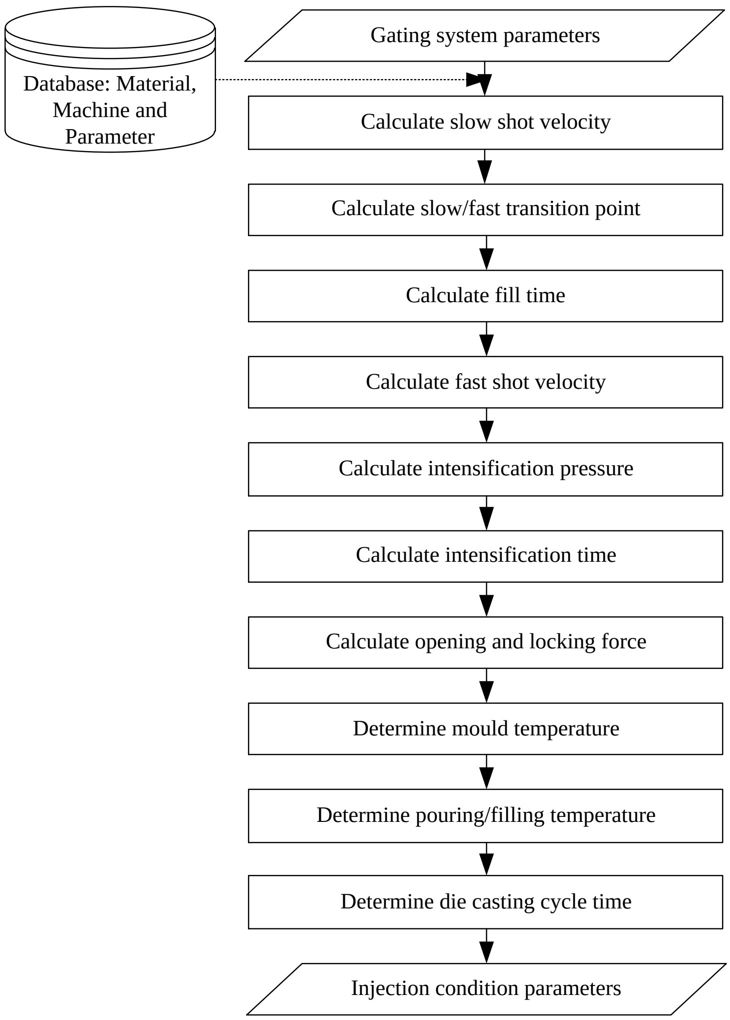

Fig. 6. Diagram displaying the procedure of determining the injection condition.

3.3. User Interface and Working of the System

In order to create and develop program according to the mold design procedure, the C# language is asked to link with the theory-referenced database by using the "Microsoft Visual Studio 2013 software" and "database organising system". To calculate the program automatically while connecting the users simultaneously, "Microsoft SQL Server 2014" is applied.

This computer aided program for aluminium die-casting mold design consists of many user interface-forms for the gating system design. The designing platform includes cavity layout design, gate area, PQ² analyzer, gate runner design, runner design, biscuit and sprue runner design, overflow design, venting design, and injection condition parameters. For the calculation of designing process, the users can interact directly with the program by inputting the information and, also, recording results via the display screen. The program can deliver and display the suggested values for designing mold condition clearly on the digital platform with different categories (i.e., several windows). Using this proposed designing platform strengthens designers and helps them make faster and better decisions in moments that matter. Illustrated in Fig. 7 is the digital area of user interface for cavity layout design developed in this research. In the user-window platform, the users can select the mold type that they would like to design by choosing the areas of interest: *the location for the feeding system*, and *the cavity layout pattern*. Moreover, the program is able to calculate the amount of possible cavity in the mold.

Interfacing platform of "PQ² analyzer" (Fig. 8) will display the assigned areas of mold design and injection condition parameters. The developed program is able to deliver the calculated values of different variables where the PQ² diagram is investigated in a systematic way. The users can quickly assign the volume flow rate; Q and metal pressure; P in the provided areas. The program will automatically calculate the gate area, the maximum fill, the time, the gate velocity, and the plunger velocity for further design. Interface for gate runner design. Next, the users can select the preferred designing types of gate runner. When the users choose to design tangent gate runner (Fig. 9), the spaces for the users to set the parameters are shown immediately for being filled. After that, the program will calculate the actual gate area and the gate runner dimension.

Figure 10 presents the interfacing platform of mold design parameters, and after calculating the gate system design completely, the designed data and the results are saved in the database and displayed as the summary of parameters in designing mold with 6 pages. These allow the users to create 3D model for the gate system of the die-casted part.

Subsequently, when the users finish assigning the injection condition, the information (i.e., the suggested designing parameters) obtained from calculating activity will be collected to the database automatically. They are concluded and formed as the summary report with 7-summary-report windows. "Page no. 1" displays the process parameter. The parameters of injection are shown in Fig. 11. Moreover. "Page no. 2 to no. 7" of interfacing screen present the designing parameters of the mold (Fig. 12).

Besides, the designing activity is displayed as step-by-step platform, so the users can easily understand the overall process of molding process. As shown in Fig. 13, the flowchart illustrates "easy-to-access" platform of the developed program and how it works in sequence.

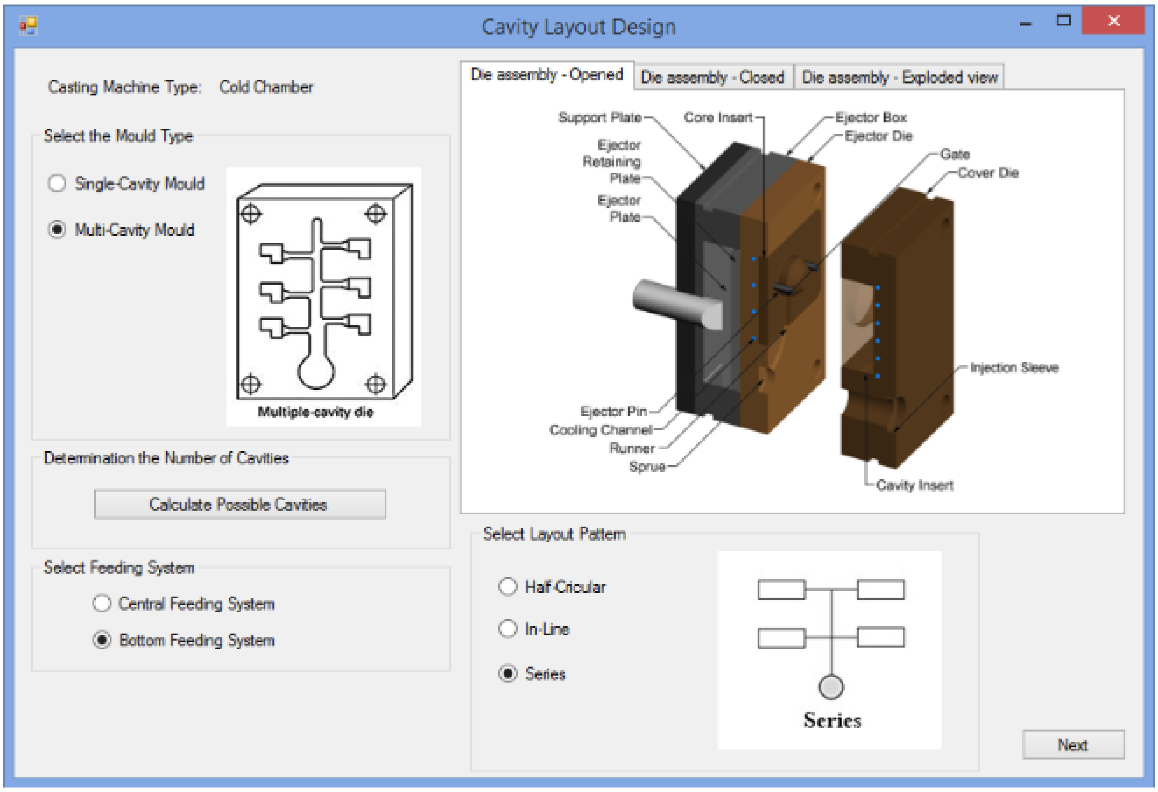

Fig. 7. A user interface for cavity layout design.

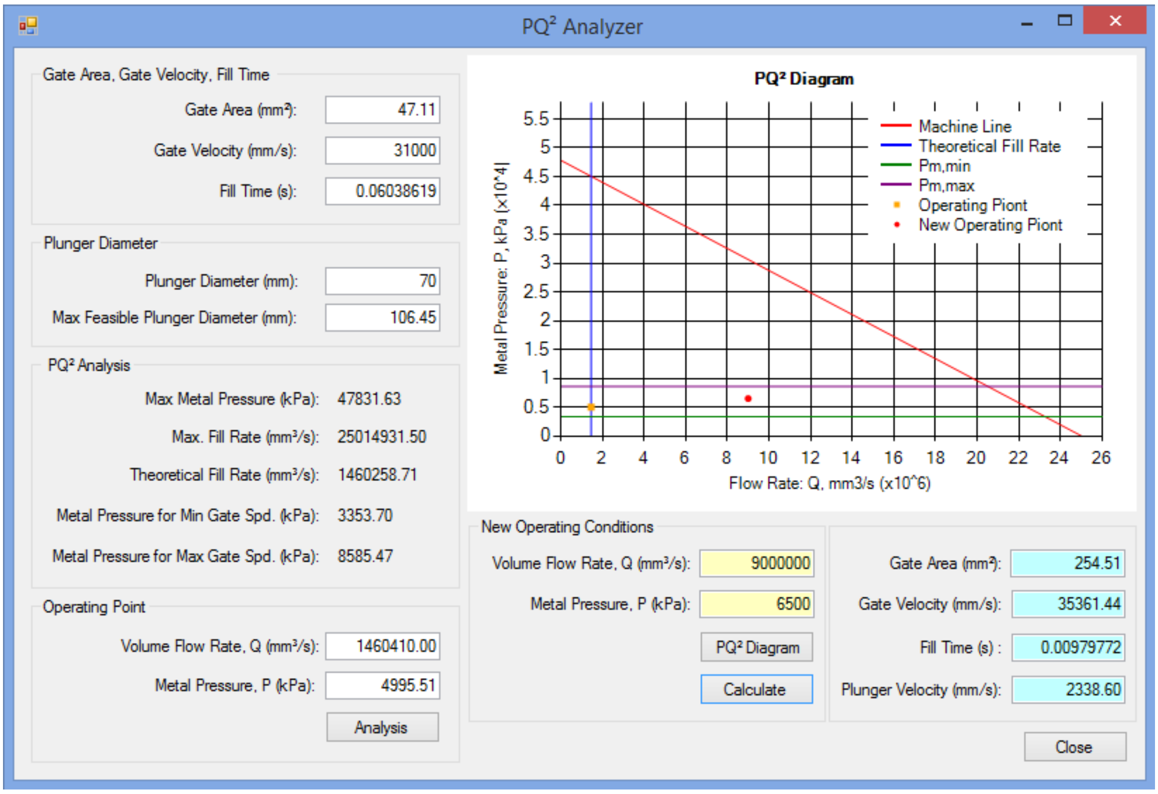

Fig. 8. A user interface for PQ² analyzer.

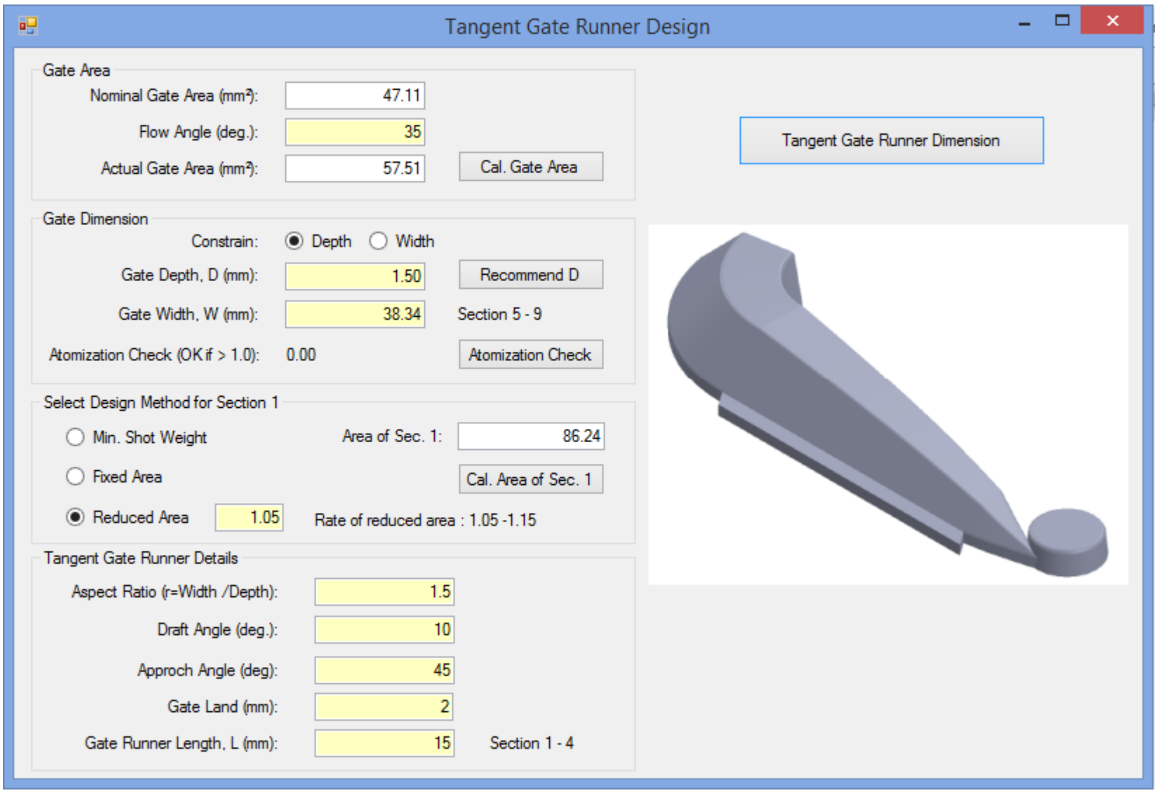

Fig. 9. A user interface for gate runner design.

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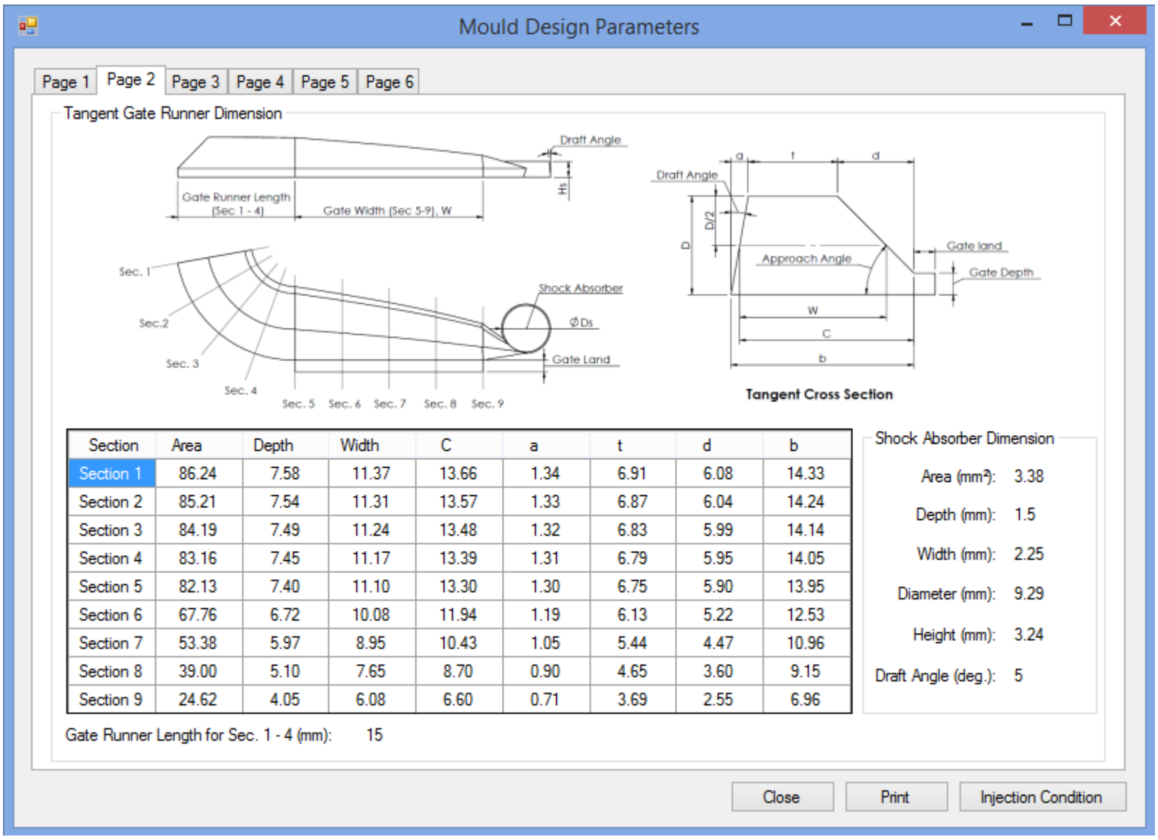

Fig. 10. A user interface for mold design parameters.

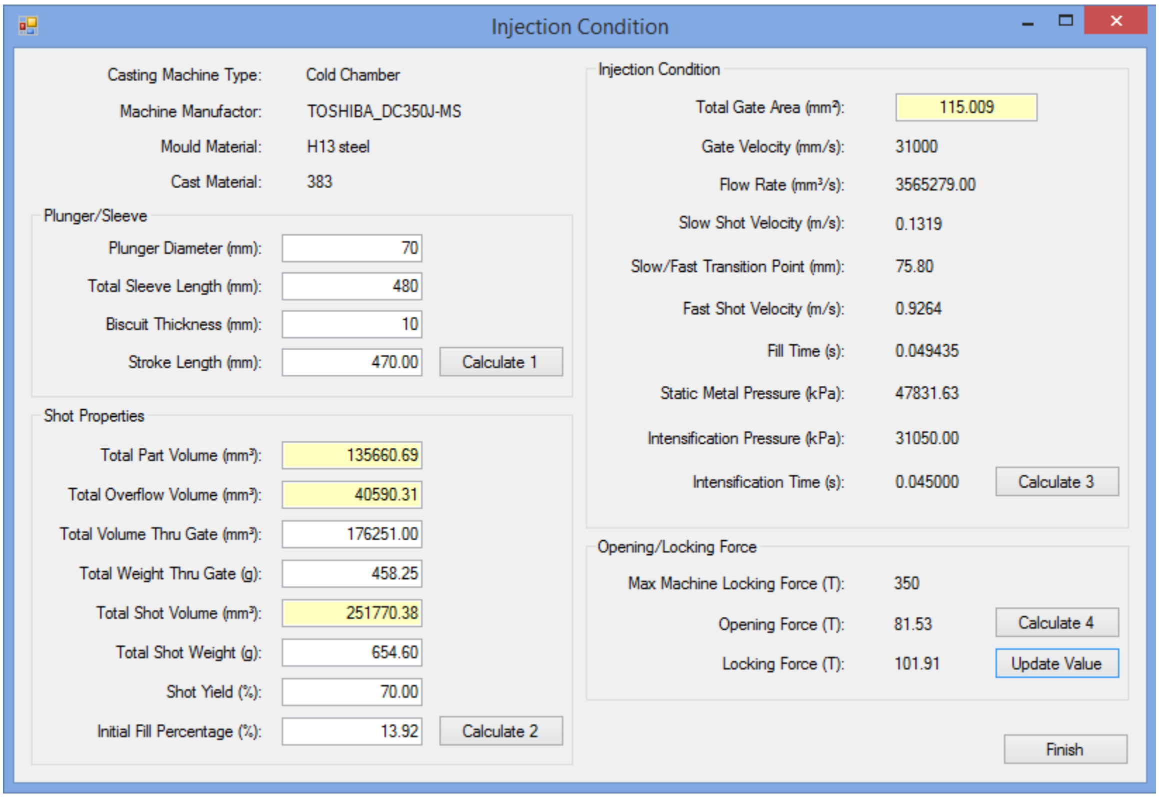

Fig. 11. A user interface for determination of injection condition.

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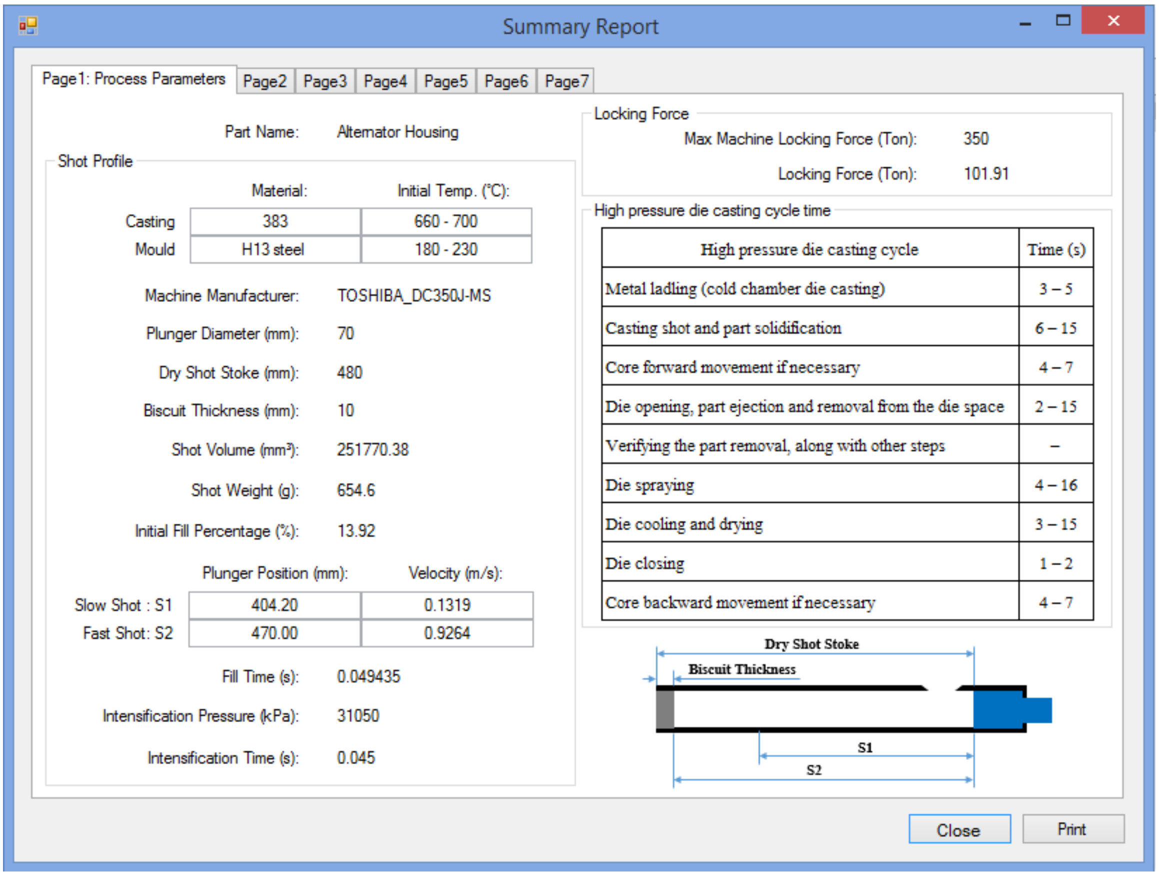

Fig. 12. A user interface for summary report of mold design and injection condition parameters.

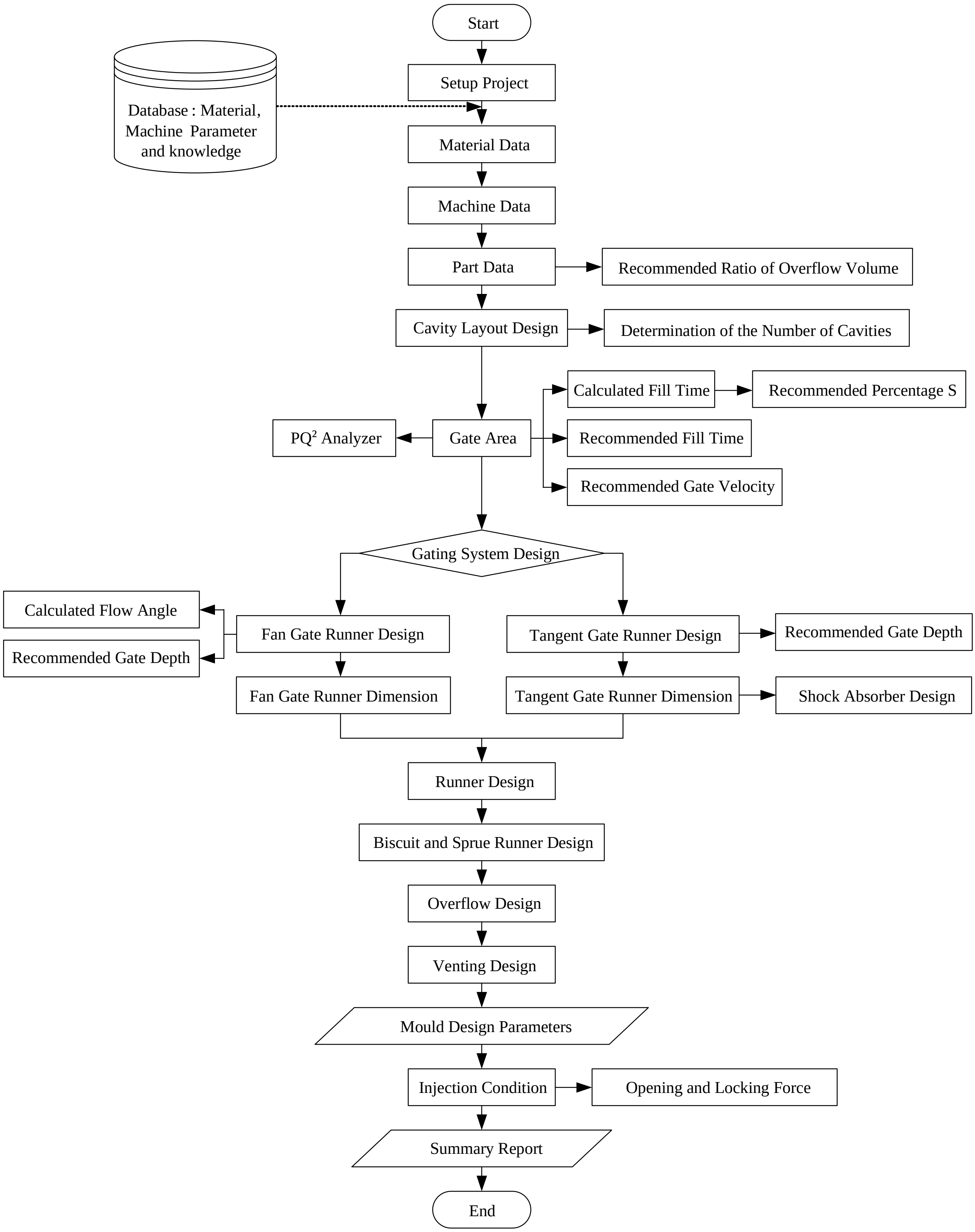

Fig. 13. Flowchart of computer aided program for aluminum die-casting mold design.

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4. Case Study

In this study, the "Alternator Housing" as shown in Table 1 was selected as the case study for demonstrating the simulating function inside the mold-flow program proposed where the parameters, the values of variables in different stages of gate system, and the injection condition were properly determined. After calculating the designed parameters, the structure of the gate system with 3D form was created according to the structure of die-casted part. The injection conditions were obtained in the subsequent step. All conditions obtained and considered; the input data, were then applied as the proper molding conditions for supporting the manufacturers to create high accuracy of the cast part comparing to the existing trial-and-error style of casting process. Moreover, in order to verify whether or not those obtained input data could support the real production, investigating-and-analyzing activity with the *MAGMASOFT Finite Element Simulation* (i.e., high-performance software of material flow simulation) was asked to perform the simulating task.

Table 1. Information of parameters in designing mold for the tested work.

Part Name	Alternator Housing (AH)
Cast Material	383 (ADC12)
Size (LxWxH) (mm)	117 x 117 x 55
Part Volume (mm³)	135660.69
Surface Area (mm2)	34372.60
Minimum Wall Thickness (mm)	3.00
Average Wall Thickness (mm)	3.95
Projected Area (mm²)	14269.60
Mold Material	H13 (SKD61)
Machine manufacturer	TOSHIBA_DC350J-MS

4.1. Results from Testing the Mold Design

According to the parameters of mold design retrieved from the program (Fig. 8 to 11) and the results from streamlining injection condition (Fig. 12 and 13), the 3D − simulation structure of the gate system made for the tested work is shown in Fig.14.

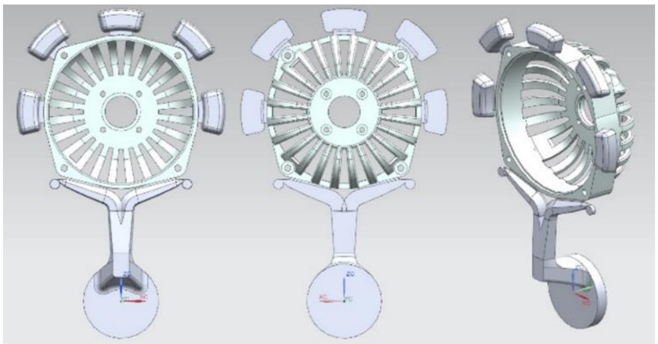

Fig. 14. The gate system made for the tested work.

4.2. Die Casting Simulation

In order to support high accuracy of the cast past, the proper suggestion or guideline of input parameters should be well provided. The researchers have tried to find ways for minimizing errors which might be found during casting activity, cross-checking or verifying the molding parameters obtained from the proposed program might be the bright direction where the high-performance software or material flow simulation should be applied.

Therefore, analysing the flow of aluminium liquid in the mold and the freezing pattern of the work with *MAGMASOFT PROGRAM* (Fig. 15 and 16) was performed in sequences. The simulation results were listed in Table 2.

Table 2. The result of simulating mold design.

Considerations	Results
Total Volume (mm³)	251,770.38
Gate Area (mm²)	115.01
Filling Time (s)	0.049
In-gate Velocity (m/s)	38 - 40 m/s for gate#1 and #2
Filling	Proper filling order; the work cavity was fully filled before overflow section was filled where the abnormal flow defect were eliminated as shown in Fig. 15.
Solidification	During the solidification within the mold, the temperature of the molten metal during solidification was uniformity throughout the mold cavity relative to the time spent and the solidification ratio as shown in Fig. 16.

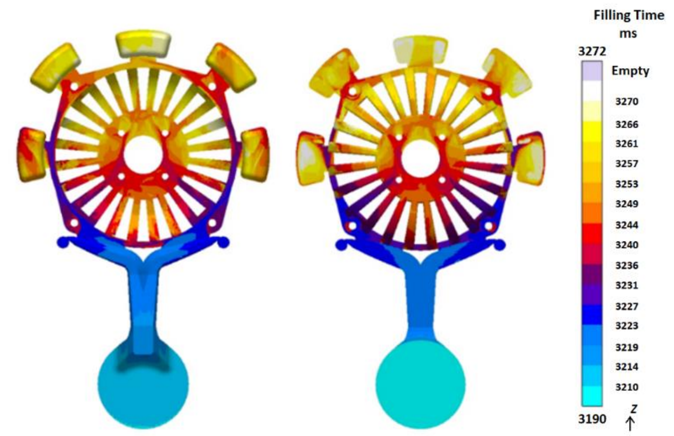

Fig. 15. Filling time (MAGMASOFT PROGRAM).

Fig. 16. Solidification temperature (MAGMASOFT PROGRAM).

5. Conclusions

Computer Aided Program for supporting mold designing platform and determining the initial injection condition for aluminium die-casting process has been introduced in this study. Applying this developed platform can provide some advantages to support the design team to create and assign the conditions of molding process properly and quickly where the failure or errors found during manufacturing process can be minimized. For supporting SMEs, this proposed program has been developed specifically to assist the customers who are working in the design and manufacturing division with easy-to-access interface. With this developed platform and the simulation packages, the requirements for major production tool modifications can be minimized. Also, it can contribute to various applications for preventing delays in processing and premature failures in service.

Moreover, in conclusion, the benefits from this developed user-friendly simulation platform can be summarized as following statements:

- The step-by-step mold design parameters suggestion from the proposed program allows the design engineers or the users who have less experiences in molding design process to assign and analyze the molding conditions easily while maintaining the accuracy of the cast part.
- The program can be applied as a tool for suggesting information about mold designing and determining the initial condition for injection process quickly and properly.
- For supporting the design of complex-gate system in die-casting mold, using this easy-to-access program can deliver and utilize the results virtually with a 3D model.
- The users can apply the retrieved injection conditions as a determinant of the parameters to initiate manufacturing process with minimizing the effect of failures due to trial-and-error assigning values.
- Since the proper molding conditions and parameters are found at the initial stage of design platform, a team can forecast the time and cost spent for doing the whole process quickly where raw material and human-labor required can be properly managed in the systematic way.
- The simulation platform provides the result of molding process more effective and robust, along with a reference standard procedure.

6. Limitations

The limitations of this study were shown through various considerations and they could be classified into these following statements.

- During mold filling, some concerning issues should to be taken into consideration and they need to be modified as up-to-date style continuously in the next episode of simulation packages; those issues are about the gas and surface oxide, which are entrapped in the melt easily. This problem causes the porosity defects and deteriorates the mechanical properties of castings.
- This 3D simulation platform, actually, is just the "virtual reality manufacturing process" that needs to be tested, checked in various ways to compare with the "real casting process". The obtained results (i.e., the cast parts) are required for reflecting the facts of the suggestions from digital analysis whether or not the users can trust and follow the guidelines from the developed software with less or no errors found.
- Since the precise comparison is not quite easy, more case studies are required and analyzed in the further works.
- Moreover, it is also very important to accurately simulate such phenomena; a fact or situation that is observed to exist or happen.

7. Contributions and Recommendations

Since during real-stage of manufacturing platform, defects or technical complaints that still need to be resolved are not reported properly in the documents to let the supervisors find out the proper methods for solving or taking proactive safety measures before an accident happens. These have led to the supportive channel to simulate or forecast the suitable parameters and conditions as "computer aided engineering (CAE) platform" to prevent any damage during performing the real manufacturing activity.

Moreover, some other problems which need to be taken into consideration are shown through: *more accurate simulation*, *direct simulation of various defects*, *and/or optimization of casting processes*. For solving these challenging problems, not only the improvement of software but also the understanding of real mechanisms of defect formation, including the relationship between the melt quality and the defects, is required.

Furthermore, it is strongly demanded to develop and progress some methods or techniques to handle the defects that happen irregularly; from the cast part, in a way that is not even or balanced in shape or arrangement. Providing the continuous efforts and knowledge from a design team can help to improve the accuracy of the software developing process (i.e., more accurate material property selection, and/or boundary conditions). The following issues are suggested and addressed for the future works.

<u>For material properties</u>

- The easy-to-access interface which has helped extend material selection platform by offering customers (designers) the ability to support team simply by quickly clicking the provided icons of material properties and casting conditions with "helps/index" to shorten time spent for identifying, and typing the specific terms of material one by one.
- At high temperature, some physical constraints and the measurement of the mechanical properties of mold and casting alloys should be well introduced and suggested.

<u>For boundary conditions</u>

- A simple platform with a practical way might be required for estimating and suggesting the heat transfer coefficient (HTC) relating to the generation of surface oxide and the presence of mold coating during mold filling.
- Clean and clear estimating the thermal resistance between the casting and the mold; including mold coating during solidification, is required. This specific estimating module might support the manufacturers to produce high precision and accuracy of the cast part while maintaining the steady state plus reliability of the molding tools.
- The surface tension of liquid metals and wetting angle with consideration of the surface oxide should be considered and estimated by the simulation for preventing any errors/defects during the real operation.

<u>For software modelling</u>

- The key point is relied on "how to make the estimation of structure and properties with reasonable resources", in which the simulation of various new casting processes should be taken into considerations via up-to-date episodes.
- Starting from the initial stage of molding process; at the pouring cup, mold filling simulation should provide the virtual fluctuation in boundary conditions with short period of time.
- Simulation packages should be implemented easily and require less input parameters where the quantitative prediction of surface depression should be presented in both 3D animation and 2D document forms.
- The difficulties found during molding process; for examples, porosity defects, gas/oxide entrainment or gas generation from coating during mold filling and solidification, flow of solid–liquid mixtures and pressure propagation in the mushy zone, should be estimated and classified into separated modules precisely to avoid misunderstandings in the user-interface platform. Moreover, short title or description should be provided after selecting.
- Since the "entrapped inclusion" leads to internal cracks; therefore the accurate simulation and prediction of this issue should be clearly defined.
- For some other issues; for examples, *deformation and residual stress*, *flow mark defects*, *making clear the formation mechanism*, *making clear the heat transfer mechanism between the melt and the evaporative pattern*, they need to be addressed and rearranged in sequences with displaying in different windows for being implemented and observed easily by the users.
- For the validation methods, the cast part and the simulated result should be well compared in digital platform. This may include the quantitative satisfaction scale or level for checking how this software package can satisfy the user's requirement via direct reports or observations.

<u>For technical supports</u>

- Some technical guidelines or user's manual should be well provided as the extra channel for being used as the practical optimization methods or the short training program.
- A fundamental concept of molding process and keywords should be guided or indexed in the "NOTE" or "SEARCH" channel inside the software package.

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