

## A STUDY OF CASTING DIE DESIGN OF BRAKE MASTER CYLINDER USING SOFTWARE SIMULATION

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### Abstrak.

Proses desain die untuk pengecoran membutuhkan pengujian yang berulang-ulang agar mendapatkan die yang baik dan menghasilkan produk yang sesuai dengan yang di rencanakan, yang membutuhkan waktu lama dan biaya yang besar untuk pembuatan die pada uji coba tersebut. Kajian ini bertujuan untuk mengetahui proses yang lebih efisien pada desain die dengan melakukan analisis pengecoran menggunakan simulasi MagmaSoft. Sample part yang digunakan dalam kajian ini adalah *master cylinder* rem sepeda motor yang akan dibuat dengan proses *Gravity Casting* dengan material aluminium. Metode dasar yang digunakan adalah perancangan die menggunakan CAD dengan memperhitungkan *Shrinkage allowance* dan simulasi pengecoran menggunakan software MagmaSoft untuk mengetahui berbagai kemungkinan cacat saat proses pengecoran seperti, *filling*, *air trap*, *solidification*, *hot spot* dan *shrinkage porosity*. Hasil simulasi menunjukkan bahwa pada proses *filling* tidak ada indikasi *cold shot*, tidak terdapat masalah *air trap*, solidifikasi dan *hot spot* bagus dan terjadi di area part, serta terjadi sedikit porosity. Secara umum hasil simulasi menunjukkan bahwa desain die ini telah memenuhi syarat, meskipun terdapat porosity akan tetapi porosity ini terjadi di area yang akan hilang setelah proses pemesinan.

**Kata kunci:** *Desain die, Gravity casting, Simulasi*

### Abstract.

The die design process for casting requires repeated testing in order to get a good die and produce a product that is as planned, which takes a long time and costs a lot for die making in this trial. The purpose of this study is to determine a more efficient process in die design by conducting a casting analysis using a MagmaSoft simulation. The sample part used in this study is a motorcycle brake master cylinder which will be made by the Gravity Casting process with aluminum material. The basic method used is die design using CAD by calculating Shrinkage allowance, and casting simulation using MagmaSoft software to find out various possible defects during the casting process, such as filling, air trap, solidification, hot spots, and shrinkage porosity. The simulation results show that in the filling process there is no indication of cold shot and no air trap problem, solidification and hot spots are good and occur in the part area, and there is little porosity. In general, the simulation results show that the die design has met the requirements, although there is porosity, this porosity occurs in the area that will be lost after the machining process.

**Keywords:** *Die desain, Gravity casting, Simulation*

## **INTRODUCTION**

The traditional design process used various tools such as rulers, pencils, drawing pens and drawing paper using manual techniques with a process that took a long time [1,2]. The recent development of technology in engineering design and drawing, allows computer applications such as CAD to assist the design process become easier and simulation software to solve the difficulties that exist in the design calculations and simulating manufacturing process, to minimize failures in the manufacture of a product [3-5].

In die casting design, the die design must be made with a high level of precision to produce a uniform and efficient mass product. Without simulation, to get a good die it needs several trials that are usually carried out repeatedly so that it is expensive, takes a long time, and causes rejected material to be wasted [6,7]. Therefore, the die making must be done in a way that an analysis can be performed right after the design is made and prior to production trial.

The simulation technology allows the design to be analyzed in advance, so that the potential product failure can be reduced and the die manufacturing process can be more efficient [8,9]. By using simulations, the die design can be checked for the possibility of porous products due to air traps, incomplete filling due to too fast solidification resulted from incorrect gate, sprue, and runner positions, and inaccurate dimensions due to miscalculation of the shrinkage of molten metal in the cavity.

This paper presents a study of die design for gravity casting process in making brake master cylinders using MagmaSoft simulation. The simulation was carried out to analyze the die design so that the casting results are good and in accordance with the specifications.

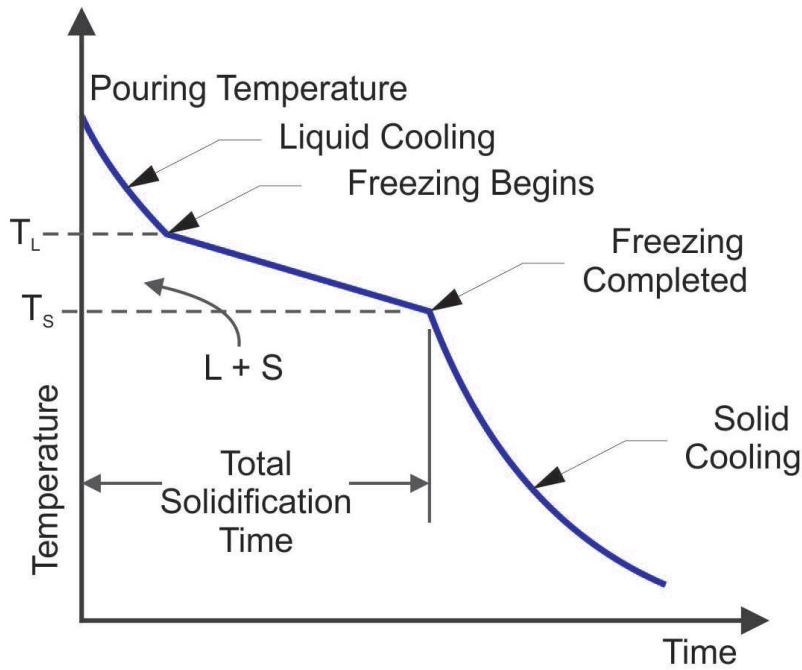
## **THEORETICAL BACKGROUND**

In comparison to high pressure die casting (HPDC) processes, production rate of gravity die casting (GDC) processes are much lower but are able to make a more complex parts, such as brake master cylinder and caliper, wheels, cylinder heads, and engine blocks. However, compared to sand casting process, GDC offers lower cost, shorter cycle times, better surface finish and internal quality [8].

For modelling interfacial flows, volume of fluid (VOF) methods is the most popular and widely used method for mold filling simulation because it is relatively easy in implementation. Several commercial simulation software for casting analysis, such as MAGMAsoft use the VOF technique [8]. MAGMAsoft is a three-dimensional package used to do modeling the flow and solidification of molten metal in dies [9]. The finite difference method is used in MagmaSoft to solve the heat and mass transfer and it is useful to simulate the flow of liquid metal in a permanent mold. MAGMAsoft can provide accurate data on solidification, velocity distribution, runner and gate effectiveness, and air entrapment.

### ***Solidification Mechanism***

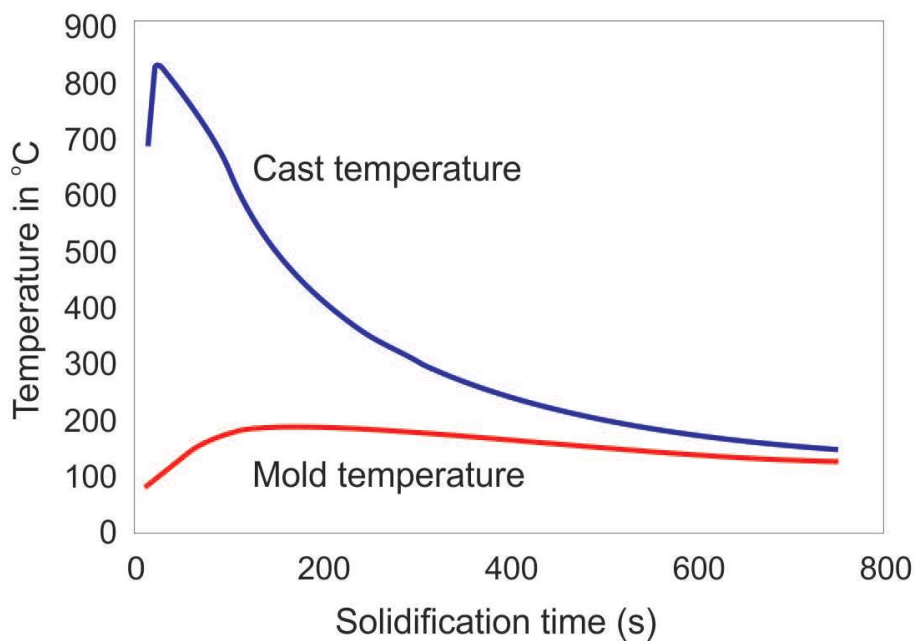
In general, solidification is initiated by pouring the high temperature molten metal into the mold cavity and it flows with a certain velocity and releases heat to the mold. The heat transfer between the mold and the cast is purely conduction due to complete thermal contact. At the time the cast metal reaches the liquidus point during the cooling process, the cast releases latent heat and at the same time also releases a number of metal oxides. This metal oxides generate an air gap between the mold and the cast. Once the whole molten metal fills the mold cavity, the temperature drops to the liquidus temperature (TL), this phase is called liquid cooling, as it is shown in Fig. 1 [10]. The liquidus temperature (TL) is the point at which the solidification begins.



**Fig 1 Solidification phase for Alloy**

As the time lapse, the solidification progresses till reach the liquidus point and the mold temperature significantly increases to maximum. Later on the outer cast surface forms a solid skin and the cast shrinks causing an air gap between the mold and the cast. As the cast temperature gradually reaches a solidus ( $T_s$ ) temperature of the alloy, the cast to releases a large quantity of latent heat to the mold.

Further solidification reduces the cast surface temperature, but the inner cast continues to release the heat to the mold and causing the rise in the mold temperature as shown in Fig. 2 [10]. During the release of heat in the inner cast metal, the inner cast shrinks and there is a possibility of releasing metal oxides which causes an air trapped inside the cast and is called shrinkage porosity. The third phase of solidification occurs as the cast temperature decreases after the solidus point ( $T_s$ ) till the end of solidification.



**Fig 2 Aluminum alloy solidification curve**

## METHOD

The method of this study is exhibited in the flowchart presented in Fig 3.

### *Part Design*

The part under study is brake master cylinder of motor cycle and the casting method used to produce the master cylinder is gravity die casting, made of Aluminum alloy (ADC12) material [13]. The 3D model is exhibited Fig 4.

The design of part for casting process should consider the shrinkage factor. The shrinkage allowance for Aluminum alloy is between 1.3 % – 1.6 % [14], and for this study the shrinkage allowance was taken at 1.5 %. Therefore, the part dimension was scaled accordingly became 1.015 from original dimension. The direction of shrinking normally to the reference point inside the dies.

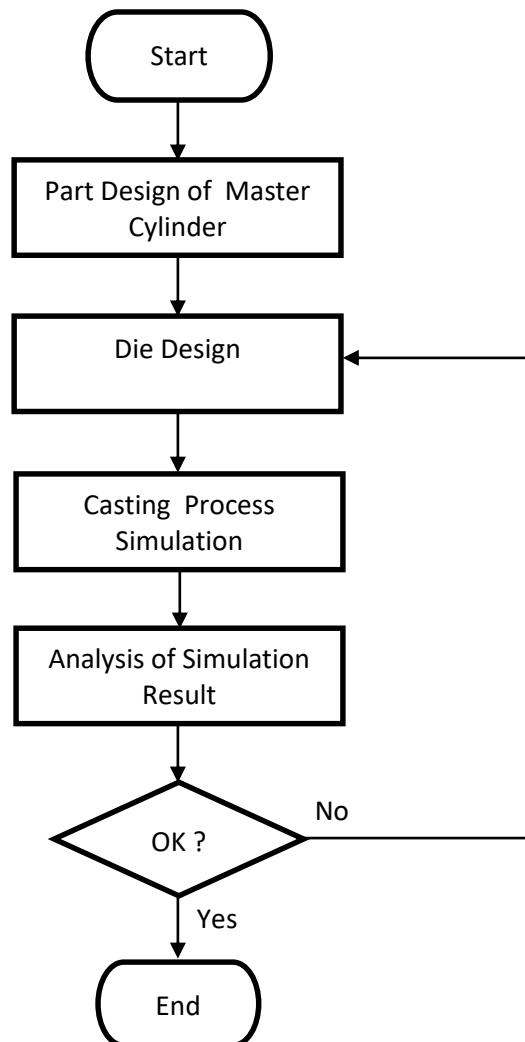


Fig 3 Flowchart of the methodology

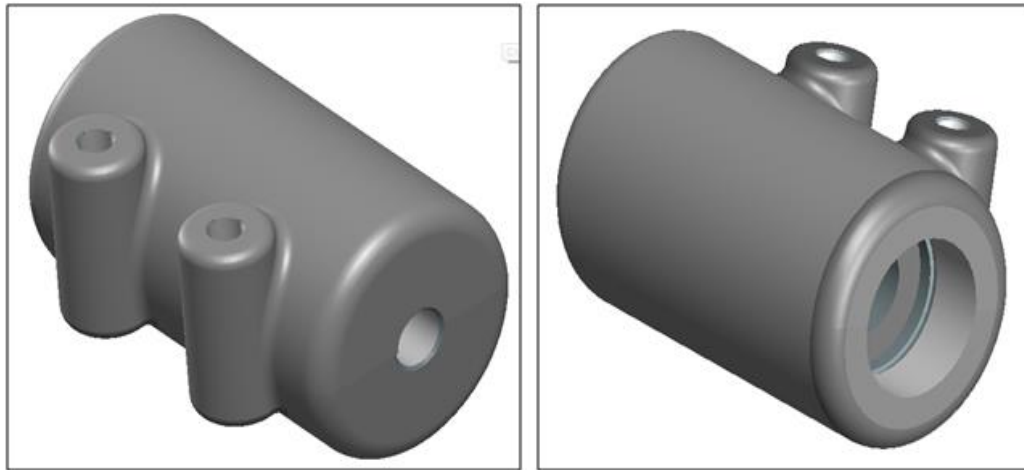


Fig 4 Master Cylinder Design

*Die Design*

The casting die was designed with two cavity model. The distribution of material volume is shown in Fig 5 and the calculated volume is presented in Table 1.

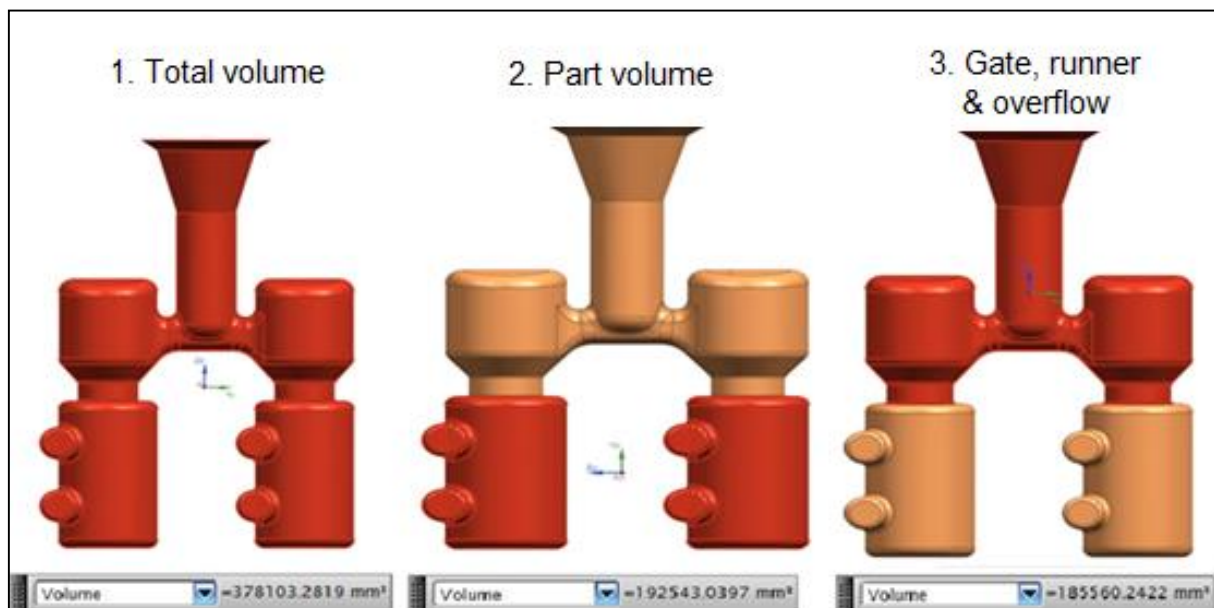


Fig 5 Part Volume

Table 1 Part Volume

No.	Item Name	Volume	Percentage
1	Total casting volume	378.103 Mm <sup>3</sup>	100%
2	Part volume	192.543 Mm <sup>3</sup>	51%
3	Gate, Runner & Over Flow volume	185.560 Mm <sup>3</sup>	49%

The detailed die design includes Runner, Over Flow, Plate Ejector and other die components are shown in Fig 6.

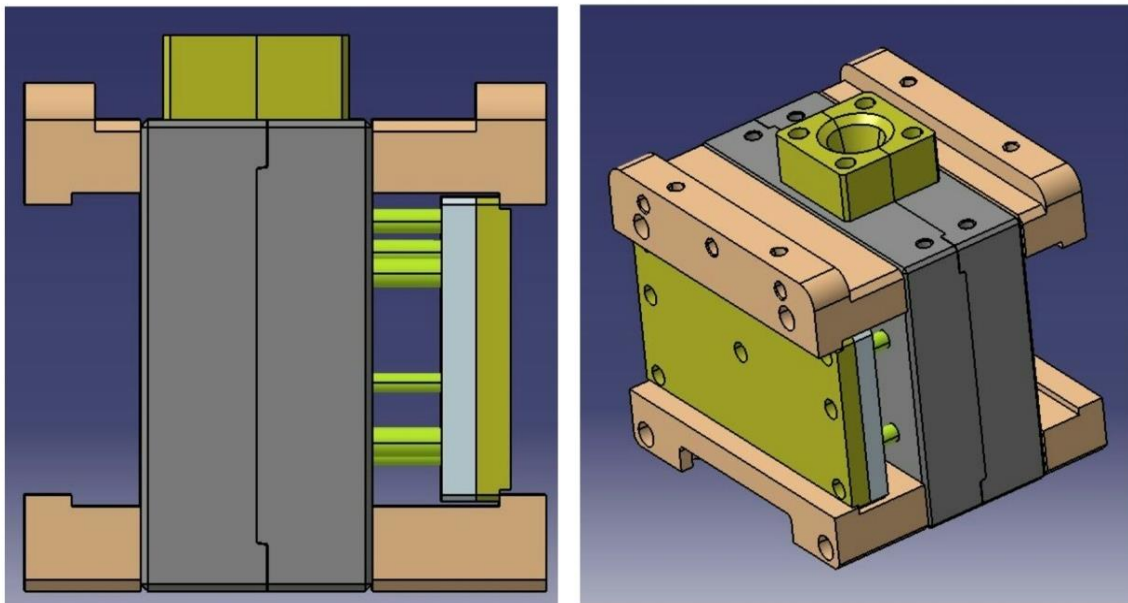
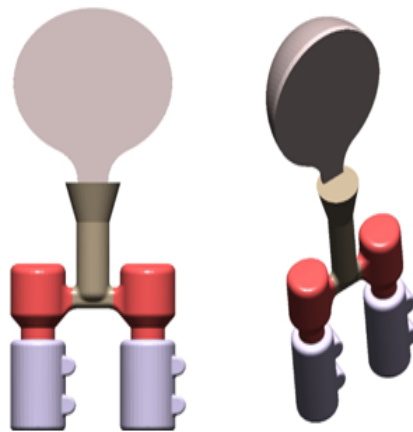


Fig 6 Die Design of Gravity Die Casting

**Casting Process Simulation**

After design process was completed, the simulation was then performed using MagmaSoft to study the casting performance and anticipate the possibility of defects. The simulation was done with the variable setting data shown in Fig 7. MagmaSoft optimize a comprehensive and effective casting process, optimize process condition, and reduce production cost. By using virtual experimental design and autonomous optimization, the strong process parameters and optimum casting layout can be determined for all materials and casting process[9].



Alloy	ADC12
Part weight	750 g
Alloy temperatur	710°C
Initial Temperatur of the steel	300°C
Time Jumping	5.5 s
Angle Jumping	70°
Solidification time	120 s

Fig 7 Variable setting data

The simulation allows evaluation of metal cooling and effective critical speed during filling. The progress and forming of porosity can be monitored and displayed continuously during solidification process.

## RESULT AND DISCUSSION

The simulation result is exhibited in Table 2

Table 2 Simulation Result

No	Defect types	Simulation	Result of simulation	Remarks
1	Filling		Aluminum casting for 6 seconds at temperature of 712°C suitable for part area	No indication of cold shot problem
2	Entrapped Air Mass		There was 8.8% air trap inside the part	Indication of entrapped air mass was small, no problem.
3	Solidification		The last solidification was inside the part	In accordance with the good practice where last solidification should be inside the part
4	Hot Spot		The hot spot fraction solid occurs, indicate the last solidification was inside the part.	There was a hot spot area inside the part, no problem
5	Shrinkage Porosity		There was a potential of porosity around 11.3 mm <sup>3</sup>	If the potential of porosity is less than 10%, the risk is very small and there is a possibility of removed by machining process

The simulation result shows a potency of small volume of porosity of  $11.3 \text{ mm}^3$  inside casting part. To cater the porosity inside the part, a machining process at the center of the part can be performed after the casting process, so that the porosity area will be removed. Hence, this part is safe to be produced without the need to modify the part design. The illustration of this process is shown in Fig 8.

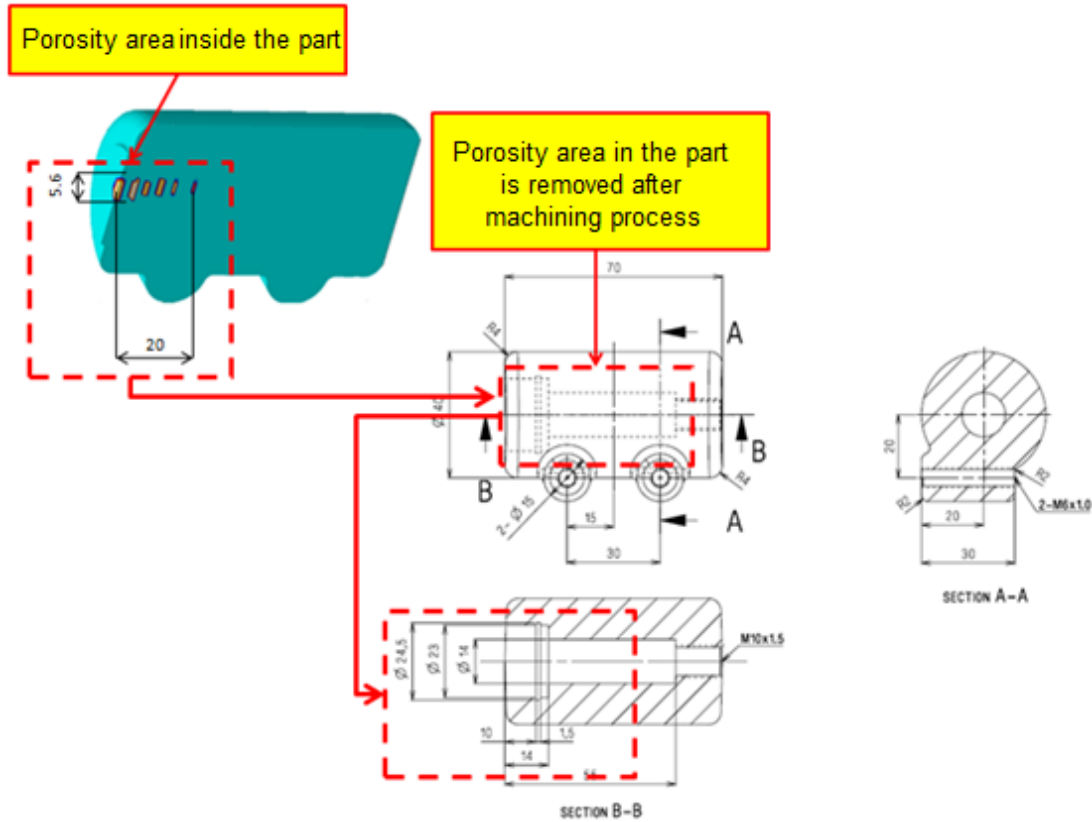


Fig 8 The Porosity in the part will be removed after machining process

## CONCLUSION

The dies that has been designed with two cavity model for gravity die casting of brake master cylinder, has an efficiency of 51 % where 49 % of material wasted in the form gate, runner & over flow. The design can be implemented into actual production by taking into consideration the variable parameters suggested by the simulation.

The simulation result indicated that filling, solidification, and hotspot are good. Meanwhile, there was a small air trap detected and also a shrinkage porosity defect. Fortunately, the porosity occurs inside the part where the machining will take place, so that the porosity will be removed and the part is safe for mass production.



## REFERENCES

- [1] A. Ozkan & K. Yildirim. Comparison of conventional and computer-aided drafting methods from the view of time and drafting quality. *Eurasian Journal of Educational Research*, 62, 2016, pp. 239-254
- [2] A.P.O. Obafemi & M.K. Oluwaseun. Effects of the Use of Computer Aided Design (CAD) On Architecture: A Quantitative Approach. *International Journal of Educational Research and Information Science*. Vol. 2, No. 4, 2015, pp. 67-76.
- [3] L. A. Bodyan, et al., Computer-Aided design and simulation of manufacturing processes in the packaging industry, 2017 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), 2017, pp. 1-5, doi: 10.1109/ICIEAM.2017.8076388.
- [4] M.R. Taleyarkhan. Investigating the impact of CAD simulations on student design thinking. Master of Science Thesis, Purdue University, West Lafayette, 2016.
- [5] A. Ramadhan, T. Atmadi & R Dinata. Utilization of Computer Aided Design Software as a Visual Simulation, *International Humanities And Applied Sciences Journal*, Volume 2, Issue 3, September, 2019, pp. 1-10.
- [6] B. Ravi. Computer-aided Casting Method Design, Simulation and Optimization. Silver Jubilee Seminar Institute of Indian Foundrymen (Indore Chapter), 13 March 2008, Indore.
- [7] I. Malik, A.A. Sani & A. Medi. Study on using Casting Simulation Software for Design and Analysis of Riser Shapes in a Solidifying Casting Component. IOP Publishing, 2019, pp. 1-7.
- [8] P. Cleary, J. Ha, V. Alguine, T. Nguyen, Flow modelling in casting processes, *Applied Mathematical Modelling*, Volume 26, Issue 2, 2002, pp. 171-190
- [9] Magma GmbH. "MagmaSoft Autonomous Engineering". [Online]. Available: <https://www.magma-soft.com/en/solutions/magma-soft/> [March, 17, 2022]
- [10] L. A. Gowsalya, and M. E. Afshan, "Heat Transfer Studies on Solidification of Casting Process", in *Casting Processes and Modelling of Metallic Materials*. London, United Kingdom: IntechOpen, 2021 [Online]. Available: <https://www.intechopen.com/chapters/74686> doi: 10.5772/intechopen.95371
- [11] V. Šabíka, et al. Optimization of a Gating System by Means of Simulation Software to Eliminate Cold Shut Defects Casting. *Journal of Casting & Materials Engineering* Vol. 5 No. 1 (2021) 1–4,
- [12] V.V. Nimbalkar et al. Analysis & Simulation of casting to eliminate casting defects. *Mythos Technology*, Volume: Vol 1, Issue: Special Issue 2, 2016, pp. 2239 – 2242.
- [13] E. Wiseno, "Simulasi Redesign Gating Sistem untuk pengecoran piston menggunakan aluminium ADC12 dengan metode Gravity Die Casting" Laporan Penelitian, Fakultas Teknologi Industri Universitas Gunadarma, 2020
- [14] S. Surupa. "Pattern Allowances for Proper Casting of Metals". <https://www.engineeringenotes.com/metallurgy/casting/pattern-allowances-for-proper-casting-of-metals-industries-metallurgy/20910>