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Techno Economic Review on Casting Design Steam Turbine Emergency Stop Valve (ESV) Housing

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Abstract*—The development of computer aided design (CAE) technology, especially casting simulation software (Magmasoft v5), can be utilized maximally as a tool to verify the design of castings that have been made to be able to meet the elements of QCD (quality, cost, delivery) and compete in the market. This study aims to obtain an optimal ESV housing casting design by reviewing and modifying the casting design in terms of both quality and economics. The process of design optimization with casting simulation is an important step in the design and development of casting products to improve casting yield and casting quality. The optimal design of castings is obtained by improving the design through pouring system using bottom pouring and optimizing the riser design. The results of this study obtained Design # 2 as a design choice of pouring system because it can improve the quality of casting products. Design # 2 optimized again into Design # 4 as the optimum design and able to increase the yield casting by 5.11% from the previous design (Design # 2). The result of techno economic analysis shows that by allocating 4% budget for design cost can contribute to decrease of production cost of foundry ESV housing up to 54,95%.*

Keywords— Design optimization, Casting simulation, Yield casting, Techno-economic.

I. INTRODUCTION

The development of computer aided design (CAE) technology, rapidly growing and becoming an integral part of industry development activities. One industry that uses CAE applications is the casting industry. Economically, the use of casting simulation is important because some advantages include: improve product quality, because casting simulation can reduce the defect of casting product, increase yield, so it can reduce feeder volume and gating channels per casting, modification to design can rapidly done, thereby reducing casting directly by trial & error. This computational method of product development is very advantageous than conventional methods (trial & error) [1]. The current casting simulation software has been widely accepted as an important tool in the design and development process of casting products that can improve casting yield and casting quality [2] [3]. Increased of casting yield can reduce cost of material, so it will be savings cost that can make the product of the cast can compete in the market [4].

Casting yield is the weight ratio of the cast product to the total weight of the casting (the weight of the cast product added with the total weight of the gating system). Increase in casting value reflects the efficiency in the casting process which results in reduced material use and reduced production costs. The riser / feeder is the heaviest component of the guttering channel (gating system) which serves to supply additional metal liquid into the mold during shrinkage in the clotting process. Depreciation is affected by the effect of contraction that occurs during freezing, either at [5]:

1. Liquid contraction (pouring temperature to liquids temperature)
2. Solidifying contraction (liquids to solids temperature)
3. .Solid contraction (solids temperature to room temperature)

So in designing of gating system should consider the existence of shrinkage factor (shrinkage allowance). In **Table 1** Shrinkage Allowance values can be shown as the amount of Shrinkage Allowance value on several main material types.

Table.1: Shrinkage Allowance [5]

Material / Metal	***Shrinkage Allowance* (% / [mm/mt])**
Cast iron	0.78 – 1.3 / [10]
Aluminum alloys	1.3 / [15]
Bronze	1.0 – 1.6 / [16]
Steel	2.6 / [21]

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Therefore, in designing of riser channel must be done optimally, because by adding the riser dimension will add casting weight and then decrease casting yield. However, if the opposite or not appropriate, it can reduce the quality of castings because of the inability to compensate for the impact of depreciation. So it is important to consider in designing of right riser either in size, shape, type, amount or placement to get quality and efficient results [6]. By casting simulation software, it can be used as a means to facilitate the design of computing and reduce the risk of trial and error in the real product.

The casting simulation is also capable of providing an overview of the casting process phenomenon which is a combination of freezing, heat transfer and fluid flow [7]. A quality and defect-free cast (soundness) can be achieved by setting the parameters [8]. So that the application of casting simulation can produce an effective cast design and identify the location of defects in the geometry of castings [9]. In general, the numerical simulation combines three fundamental equations, the law conservation of mass, momentum and energy [7]. In addition to these three equations, the law of fluid flow should also take into the laws of Bernoulli, Reynold Number and Navier-Stokes. Since this casting simulation is a complex phenomenon, the assumptions and limitations used in the casting simulation must be considered in order to obtain a representative result [9]. On the other hand, the casting simulation is just a representation of the modeling, so it can not represent the actual product of the castings, because the arrangement of the casting simulation process parameters must be close to the real condition and the result of the simulation needs to be done in more depth analysis [10].

In this research, a techno-economic study of casting simulation will be done on the manufacture of emergency stop valve (ESV), which is one of the component parts in the steam turbine as a throttle valve. ESV should be able to stop the vapor flow quickly and completely, either automatically or manually when needed. ESV components are enclosed by an ESV housing that to maintain pressure from leakage and protection part from foreign objects. In the manufacturing process, ESV housing is divided into 4 parts, the top, middle, bevel and lower casing. The middle ESV housing failed when casting process occurs frequently. The Geometry of ESV can be seen in Figure 1. The ESV housing material is made of high-pressure, high-temperature JIS G5151 Grade SCPH2 steel. While the manufacturing process of ESV Housing steam turbine is done by using the casting method (sand casting) and its completion with machining process. The reason to study about techno-economic of casting simulation in manufacturing process is several failures in casting ESV housing at the beginning of the prototype. Indication of failure is the existence from defective castings (crack and porosity of casting products). The failure of casting process is probably due to errors in the design of the channel system and the raiser system. By using casting simulation is expected to reduce the amount of casting by trial error, also minimize the occurrence of casting defects.

The design optimization process of ESV housing, which has been preceded by a casting simulation using Magmasoft v5 with required quality must meet the standards for JIS G5151 Grade SCPH2 and ASTM A 609 quality level 2. This research, will be focused on optimizing the design of the castings (improvement), which used existing design with an orientation of increasing yield casting values and a review of the techno-economic analysis for the ESV housing casting process.

Fig.1: ESV Housing

II. RESEARCH METHOD

The development of this research is focused in design of ESV housing casting products that have been produced with the aim of increasing casting yield and for conducting a techno-economic review study with quality castings referring to the required standards of JIS G5151 Grade SCPH2 and ASTM A 609 quality level 2 materials. The optimization design of castings (improvement) is already done by using the method of comparison both technically and economically (techno-economic) between product in early castings to the results of design optimization using casting simulation software, Magmasoft V5.

Through the use of Magmasoft software v5 shrinkage effects that occur can be predicted, so it can facilitate in optimizing the design without using actual casting products to get optimal design results. Reducing the riser height in the riser area can increase the yield casting as illustrated in Figure 1.

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The research was conducted with an orientation on increasing casting yield and quality by comparing the first rejected design and two alternative design that already improved and optimization from the best design alternatives. Optimization through this decrease of riser height method is ~ 30%, based on previous simulation ,the result of analysis showing potential riser area to be optimized, because the impact of shrinkage that occurs in the riser area is still far from the castings, as can be shown in Figure 2 Potential Area for Upper Yield Casting below.

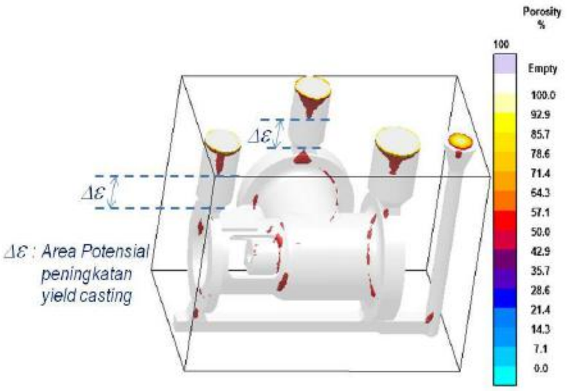


Fig.2. Potential areas to increase Yield Casting

Step of this research is:

a. Design optimization, design and simulation casting for:
   - ❑ Design #1 :Result of first casting (*rejected*)
   - ❑ Design #2:alternative first improvement design
   - ❑ Design #3:alternative first improvement design
   - ❑ Design #4:optimization of repair design

b. Study of Techno Economic
   This study is based on cost of material usage that calculated from this equation [11].

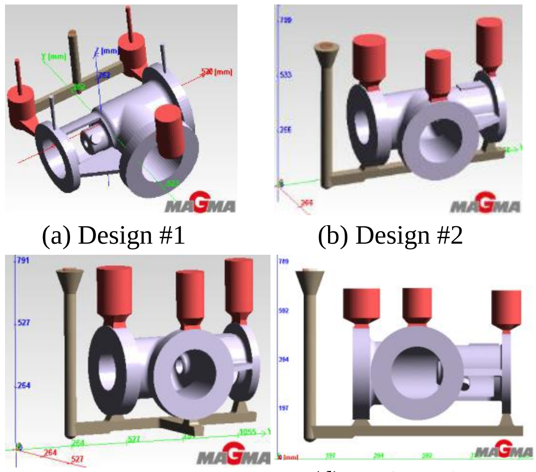
$$C_{metal} = C_{unit\ metal} \times W_{cast} \times f_m \times f_p \times f_f \times f_r \qquad \textbf{(1)}$$

C_{metal} :Metal or material Cost (Rp)
$C_{unit\ metal}$:Unit price of material (Rp /Kg)
W_{cast} :weight of *casting* (Kg)
f_m :Materials loss during melting factor (1,01 – 1,12)
f_p :Materials loss during pouring factor (1,01 – 1,07)
f_f :Materials loss during finishing factor (1,01 – 1,07)
f_r :Rejection factor (Steel: 1,00 – 1,12)

Parameter and boundary condition are described :

a. CAD Software :CATIA V5 R19
b. CAE Software :Magmasoft v5
c. Solver :Solidification
d. Method :Gravity casting
e. Materials :ASTM A216 ≈JIS G5151 Grade SCPH2
f. Mold :Green sand
g. Casting Temp :1.680ºC
h. Casting Time :30 sec

III. RESULT AND ANALYSIS



(a) Design #1 (b) Design #2

(c) Design #3 (d) Design #4

Fig.3: 3D Gating System Design

In this study there are four designs to be analyzed, as shown in Figure 3 3D Gating System Design. Design # 1 was an initial design that had been cast without preceded using Magmasoft simulation analysis and failed. Then the analysis and comparison between non-destructive test results - Ultrasonic Test (NDT-UT) of castings product with Magmasoft simulation results, as shown in Figure 4 Comparison of NDT-UT vs. Magmasoft.

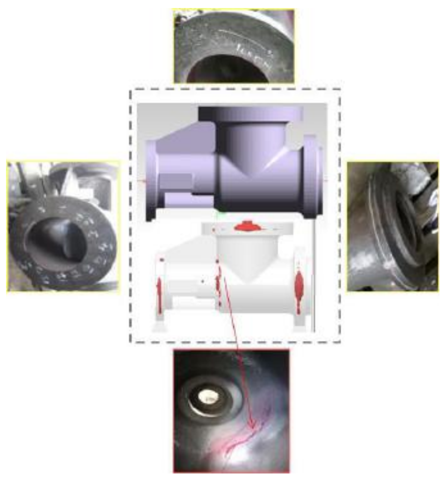


Fig.4: Comparison between NDT-UT vs Magmasoft

From the comparative analysis can be seen that the suitability location of porosity between NDT-UT and Magmasoft simulation, in the third area of radial flange direction and area of center of body valve. Porosity is a type of defect that commonly encountered in the presence of cavities in casting products that can be caused by:

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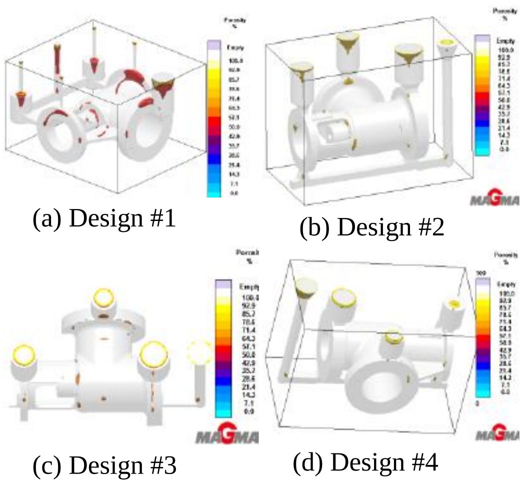
- The gas content in the melting process
- Air and gas trapped during charging
- The metal shrinkage when freezing
- And combinations-combinations

The initial analysis results about pattern need to be changed with consideration of flow improvement to minimize turbulence during liquid metal filling by changing side pouring to bottom pouring and cast-ability design improvement by providing additional machining allowance in flange area. In addition, different wall thickness variations lead to varying cooling rates, to compensate shrinkage and to seek directional solidification need an adequate riser system.

The concept of design change is added into Design # 2 (using 2 in-gate) and Design # 3 (using 3 in-gate). In general, the results of Design # 2 and Design # 3 are almost the same in quality but Design # 2 has higher yield casting, so Design # 2 is chosen to be optimized to increase casting yield to be Design # 4.

3.1 Design Analysis And Simulation

Based on the simulation results with solidification criteria - porosity as shown in **Figure 5**, the four designs of ESV housing have defect potential trend in same area that is in the flange and middle body valve connection area



(a) Design #1 (b) Design #2

(c) Design #3 (d) Design #4

Fig.5: Result of design simulation and porosity

In the quality of the simulation results, the maximum potential defects are shown in Design # 1 and at least in Design # 4. In Design # 4 has a better quality of casting results based on the color gradation in the range of 80-90%. The results of the research optimized the design of ESV housing castings, as compared to the increase in yield casting from each design experiment can be shown in Figure 6. Design # 1 is the highest efficiency (yield casting) but the lowest quality. Therefore, other design alternatives are sought, Design # 2, # 3 and # 4 have a larger product weight due to the addition of machining allowance for product quality repair efforts. When compared, Design # 4 is more efficient with product weight 181.3 kg, weight gating system 72.37 kg and casting yield value of 71.47%. The results of a survey conducted in the American casting industry that the value of casting yield for steel castings with a mass of about 55% weight and the value can be increased for smelting the lighter steel [12]. So the yield casting value for this ESV housing is still relevant for the casting process..

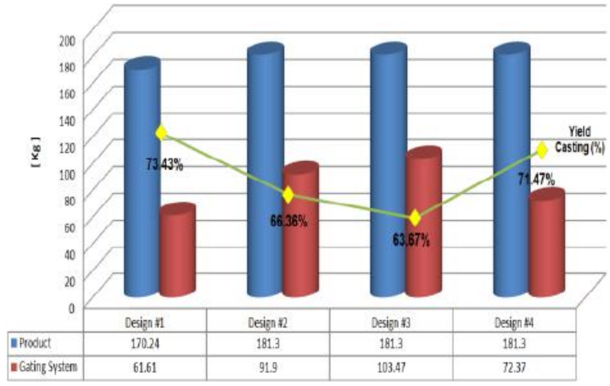


Fig.6: Comparison of Yield Casting

The Magmasoft software makes it easy to design in trying various gating system designs to get the most optimum design in terms of quality and efficiency. The result of design and simulation analysis, Design # 4 is the most optimum design. In addition, the ability of the simulated casting software Magmasoft to predict areas of potential defect can be used as input at the time of the casting process, for example by the use of chill and chromium sand on the walls of the casing which is critical to help freezing process.

3.2 Analysis of Techno-Economic

The details of casting process cost consist of several elements ranging from material purchase, design, production, testing to profit, which depends on the process being applied [13]. This can be illustrated as shown in Figure 7 below.

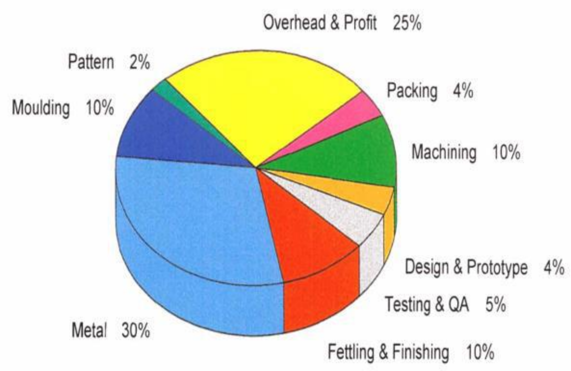


Fig.7: Detail of casting cost[13]

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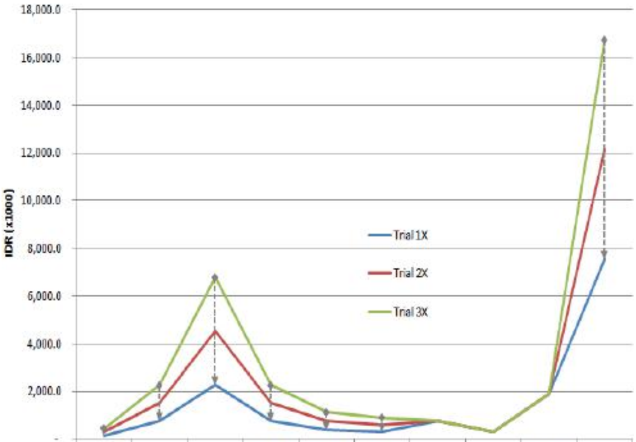
If assumed that without a simulated casting process, it requires more than one casting time to compensate the risk factor of failure. Repetition can be done for 2 or 3 times experiment, especially for the cost of making pattern, molding, metal, finishing (as cast), testing, design - prototype. Systematically the results of techno-economic analysis for ESV housing casting can be illustrated as shown in Figure 8.



	Pattern	Moulding	Metal	Fettling & Finishing	Testing & QA	Design Prototype	Machining	Packaging	Overhead & Profit	Total Cost
Trial 1X	150.7	753.5	2,260.6	753.5	376.8	301.4	753.5	301.4	1,883.9	7,535.5
Trial 2X	301.4	1,507.1	4,521.3	1,507.1	753.5	602.8	753.5	301.4	1,883.9	12,132.1
Trial 3X	452.1	2,260.6	6,781.9	2,260.6	1,130.3	904.3	753.5	301.4	1,883.9	16,728.7

Fig.8: comparison of casting cost

The total cost of casting can be deal with 3 times are about 16.728 million rupiah, while if the simulation design optimization process succeeded in making the cast product 1 times the casting execution then only requires production cost of 7,535 million rupiah. So by allocating casting design cost of 4% optimally able to contribute to total production cost up to 54, 95%.

IV. CONCLUSION

Optimization and design selection using the casting simulation method (Magmasoft) can produce a design castings that can improve casting quality and yield casting. The simulation results can also be used as inputs in conducting preventive actions to prevent potential defects occurring during the casting process execution. Design # 4 is the design of choices that lower the potential for defects and lower production costs by 54, 95%.

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