
ПРОБЛЕМИ АВТОМАТИЗАЦІЇ, МЕХАНІЗАЦІЇ ТА КОМП'ЮТЕРИЗАЦІЇ ПРОЦЕСІВ ЛИТТЯ

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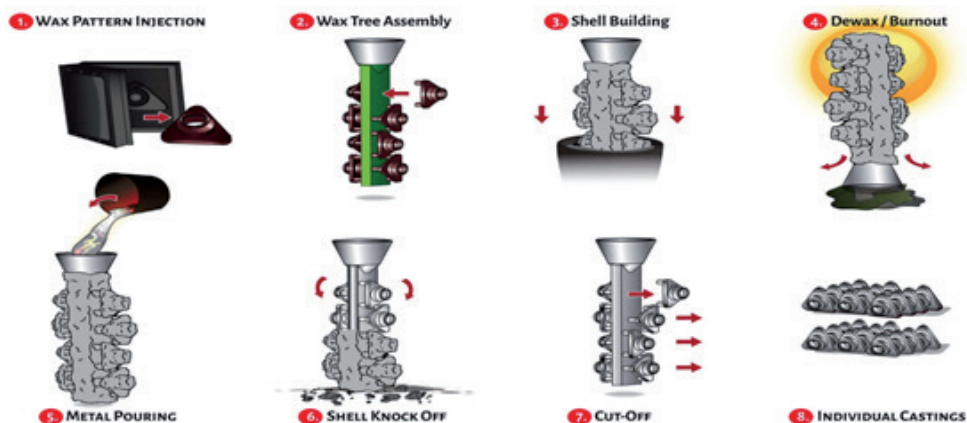
INVESTIGATION AND OPTIMIZATION OF CASTING DEFECTS OF REAR SIGHT BASE PART OF AK47 DEVELOPED BY INVESTMENT CASTING PROCESS

Investment casting (IC) process is a manufacturing method for many critical and value added components in many industrial and commercial applications. Today, all the precision components of medical, defense, automobile industries, and other industries are being manufactured using the IC process. IC may experience different defects such as crack, porosity, hot tear, shrinkage, blowhole etc., because of poor design of gating and riser system, and inappropriate selection of process parameters. The casting of Rear sight base is a difficult operation due to its complex shape and thin wall structure. For such components with complex geometries, defects such as hot tearing, shrinkage porosity etc., are common and need to be addressed. Causes of defects have been investigated using interview, observation, group discussion, and Non-destructive testing (NDT) method. From the investigations, high percentage defect and influential parameters were selected based on the cause-effect diagram method. Optimization of process parameter such as getting length and pouring temperature were analyzed using ProCast software. The simulation contains the analysis of finite element method (FEM), simulation of fluid flow and solidification of metal execution of various pouring temperature and getting length for prediction of shrinkage porosity and hot tearing/crack allocation/percentage. From the simulation result optimum pouring temperature and getting length have been selected. For the optimized getting length of 17 mm, 0% hot tear and 0.669 % shrinkage porosity defects were observed. The optimized pouring temperature was 1630 °C for the production of rear sight base components using investment casting. For the getting length of 17mm and optimized pouring temperature, shrinkage porosity was reduced by 40.93 % and hot tearing/crack was reduced by 9.4 %, compared to the former scheme (1580 °C pouring temperature, 15 mm gate length).

Keywords: investment casting, FEM, procast software, defects, rear sight base.

INTRODUCTION

Lost wax casting (investment casting) production process is a mix of handwork, semiautomatic and control operations, it can be divided in the following main steps: Wax die injection, Mould assembly, Mould shelling with ceramic slurry and refractory powders, De-waxing, Casting Knock out, Finishing operations NDT controls. The production process consists of an initial phase of injection of “models” of wax components which, when assembled in clusters, are then covered in shell area with refractory ceramic materials that can withstand at high temperatures. The wax is removed and the ceramic shell is sintered. At this step it becomes ready to receive the metal pouring during the CAST phase [1][2] [3].



[2] Figure 1. Investment casting (lost wax process)

The process is very complex due to the influence of a wide range of variables, consequence of heterogeneous materials and of a large variety of processes involved in the investment casting operations. It seems clear that actual controls are not enough to guarantee a zero- defect process, which can mean that: unconscious of all critical parameters, Actual process tolerances are not fully identified. Casting process is “unstable” by nature, not “robust”. [2] Hence how to improve the casting quality and reduce defects becomes important. Casting quality is mainly dependent on the systematic gating and risering design, which is mainly relied on workers experience. Computer assisted casting solidification process helps the foundry industries to optimize the design parameters, better understand the mould filling and temperature history of the solidifying castings hence to identify the defects with the aid of obtained time-temperature contours.[4] Based on different literatures, it has been found that most analytical studies were on investment casting of influential process parameters. Many researchers have studied the effects of process parameters (i.e. shell thickness, pouring velocity, pouring temperature, pouring time, getting and riser system, preheat time, moisture content, binder percentage, etc.) based on deferent quality characteristics.[5][6][7] Most literature studied towards minimizing of casting defects and improving quality of production by applying analytical method using different commercially available software package (MAGMASoft, ViewCast, Any Cast, ProCast, etc). Depends on the software analytical methods are different like; FEM (Finite Element method), FDM (Finite difference method).[8][9][10]incomplete filling, and gas porosity in a rotor might cause creep failure, which can be dangerous during operation. Therefore, computer-aided modeling and experimental verifications are conducted in this work to optimize the investment casting of rotors. Six casting processes and five gating system schemes are designed to optimize the casting qualities. The probability of defect occurrence during casting is assessed based on the retained melt modulus incorporated with the Niyama criterion model. Numerical simulation and experimental results show good agreement. Thermodynamic analysis results show that a high cooling rate increases the flow resistance of molten metal between the dendrite arm spaces, resulting in insufficient feeding in the mushy zone. With proper designs of the runner and riser systems, the problems of flow turbulence and insufficient feeding are almost obviated. Surface sinks and interior shrinkage are also completely eliminated.”, "author": [{"dropping-particle": "", "family": "Huang", "given": "Pei Hsing", "non-dropping-particle": "", "parse-names": false, "suffix": ""}, {"dropping-particle": "", "family": "Lin", "given": "Chi Ju", "non-dropping-particle": "", "parse-names": false, "suffix": ""}], "container-title": "International Journal of Advanced Manufacturing Technology", "id": "ITEM-1", "issue": "5-8", "issued": {"date-parts": [{"2015"}]}, "note": "By conducting computer-aided design and experiments, the investment casting process of a high-speed rotor was optimized in this study. Using mold flow analysis, the thermodynamic behaviors and fluid transient phenomena during the pouring process were predicted. The pouring quality and

defect formation probabilities were also assessed and verified via experiments. The key findings are as follows:\n1. Using low pouring and shell mold temperatures accelerated cooling rates at the thin-walled sections. The resultant residual stresses caused surface deformation and increased the probability of shrinkage porosities.\n2. Overly complicated runner designs (cases 1–4[11][12] In investment casting, for past several year computer aided modeling has been helping the foundry, not only for design of new components, but also used in redesigning the existing one. Also eliminates product defects without trial and error, and reduce scrap and rework. The investment caster can achieve more consistent product quality and improvements and obtain higher yields. Process parameter optimization is a key step of in analytical method to achieve high manufacturing yield without increasing cost of production. Optimization of design system by applying through analytical method helps to reduce trial and error cost, time, energy, and scrap percentage in any casting process.[13][14]

Hence, this work proposes an effective process parameter (i.e. pouring temperature from process parameter and gating length from design parameter) optimization approach to assist investment casting process. Inappropriateness of this two parameters greatly results defects, in case shrinkage porosity is directly related with the fluidity and flow-ability of the molten metal so that its better to optimize the pouring temperature of the metal. In other hand, internal crack, misrun and the like defects are formed due to the wrong design of gating system therefore the better option to minimize those defects is optimizing the gating length. Determining the parameter settings for casting greatly affects the quality of the product. Inappropriate process parameter settings can cause many production problems (e.g. defects, long lead times, large amounts of scrap, high production costs, etc.), increase the price competitive advantage, and reduced a company's profitability. Generally, the area is still its active research area so, this thesis contribute a great improvement on understanding and control of defects in investment casting process. From the above reviewed literature it has been found that there is not sufficient research works has been done on the medium carbon steel component. In this present work, the medium carbon steel is the major casting material which is used for producing Rear sight base in GAEI. Also in this research both design and process parameters are optimized together through commercially available software called PROCAST based on FEA method. This work studies the root causes of defects using (literature survey, interview, discussion, and different NDT testing technique) during the investment casting process. Investment casting defects such as shrinkage porosity and hot tear/crack are controlled independently depends on deferent condition. Parameters such as gate length and pouring temperature are identified depend on cause and effect method used to optimize those defects. Optimum pouring temperature and gate length should select using ProCAST software.

METHODOLOGY

Material

For proper functioning, the rear sight base the following condition should fulfill after production.

Having enough strength to withstand the force which is subjected to twisting and bending moment.

It must be defect free , defects like crack, shrinkage, porosity, misrun and the like.

Minimum weight i.e. rear sight base is a part of small armament.

Enough stiffness and rigidity.

Generally, Rear sight base is one part of ET 97/01 AK47 automatic rifle which is manufactured by investment casting process in Gafat armament engineering industry. It is used to attach the barrel and receiver mechanisms, and also holds the gas tube and rear sight leaf. Its material should properly cast, heat treated, machined and have adequate hardness, strength, toughness, and high wear resistance capacity. The rear sight base part material used in this study is cast steel (AISI 1050) which is medium carbon C50.

Method

The methodologies that used to achieve the objectives are qualitative and quantitative methods for investigation of cause of defect and simulation software package for

optimization. The steps that followed for investigation and optimization are: Physical observation of all the process, Personal interview (in order to observe relevant information, and conducting discussions with workers/operators, supervisors, design section and the factory manager), Identifying the problems in scientific view in each process. Conducting NDT test for identifying defects, According to the observed data concluded. that the root causes of defects depend on literature, Identify the influential parameters which are directly related to the cause as well as the defects using cause and effect diagram, Selecting the main parameters and its level, The setting of the process will determine by Finite Element Method, and then Tools such as FEM, and PROCAST software package used.

Procedures for optimization of parameters

Analysis method of bending and shear stress of AK47, Finite element analysis, Mesh generation, Pre processing , Post processing for each optimizing parameters, Simulation of each process characteristics, Result of cracks and shrinkage porosity individually and discussion.

RESULT AND DISCUSSION

Investigation of casting defects

Through the process of finding the root cause of defects the primary step is identify and understand the defects which the major cause for the rejection. In this section defects of rear sight base componets has investigate by using interview/observation/group discussion and testing methods. According to the above introduction the investigation could be done in the following methods: Interview, discussion, and physical observation to Identifying the problem in each process of producing rear sight base componets, NDT testing method, visual testing, Liquid Penetrant inspection methods, Magnetic field inspection method. From the above investigation, commonly observed defects are shrinkage porosity, hot tears, internal and surface crack and misrun. Generally, the above investigated defects are common in the rejected components of rear sight base part. The test results revealed that most of the defects are shrinkage porosity and cracks. The root cause of shrinkage porosity is due to inappropriateness pouring temperature, when the pressure of metal is too low, poor getting and riser design and complexity in casting geometry. Although the root causes of crack/hot tear are problem of getting system, thermal contraction, tin section and incorrect metal pouring temperature. [15][16][7]

Optimization

In this section, results in terms of hot tearing/crack and result in terms of shrinkage porosity have been presented. For each of the given getting length (14 mm, 16 mm and 17 mm) by changing the pouring temperature as (1570 °C, 1600 °C, 1630 °C) both hot tearing/crack

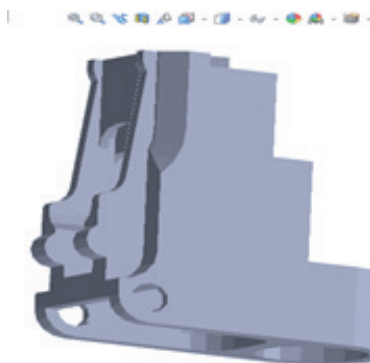


Figure 2. 3D model of Rear sight base (generated by SOLIDWORK)



Figure 3. Visual testing, casting defects (misrun and shrinkage porosity) and crack



Figure 4. Result of liquid Penetrant inspection, casting defect hot tearing/crack



Figure 5. Process and results of magnetic particle inspection method, result shows there is some void/crack/hot tearing

in this section the effects of pouring temperature and getting length for the formation of hot tearing/crack and shrinkage porosity were simulated and presented using ProCast casting simulation software accordingly.

Result in terms of hot tear/crack

Here results in terms of hot tearing crack were presented for getting length 14 mm, 16 mm, and 17 mm. for each of the getting length three pouring temperature which are 1570 °C, 1600 °C and 1630 °C were simulated using ProCast software for recognize optimum parameter for the production of rear sight base component developed by investment casting process.

Results for getting length 16 mm with different temperature

16 mm getting length is greater than 1 mm from the initial design, the simulation result shows the stress and fluid flow effect when the getting length is reduce by 1 mm. when the getting area is increase tensile stress is decreased due to their inverse proportionality. Here expected to get minimum hot tear defects in moderate temperature.

Results for getting length 17 with different temperature

17 mm getting length is greater than 2 mm from the initial design, the simulation result shows the stress and fluid flow effect when the getting length is reduce by 2 mm. when the getting area is increase tensile stress is decreased due to their inverse proportionality. In 17 mm more expected to get minimum hot tear defects in optimum temperature.

Result in terms of shrinkage porosity

Here results in terms of hot tearing crack were presented for getting length 14 mm, 16 mm, and 17 mm. for each of the getting length three pouring temperature which are

and shrinkage porosity have been simulated and clearly discussed. Finally the optimum results have been selected and compared with the initial design by using ProCast casting simulation software.

Results

Pouring temperature determines the temperature distribution, fluidity and built-up of press, and thermal stress in casting. Hot tearing/crack may be avoided by pouring the molten metal at moderate temperature. Shrinkage porosity defects results from the phenomena such as fluid flow, heat transfer with solidification, feeding flow and its free surface, and so on. Therefore, in

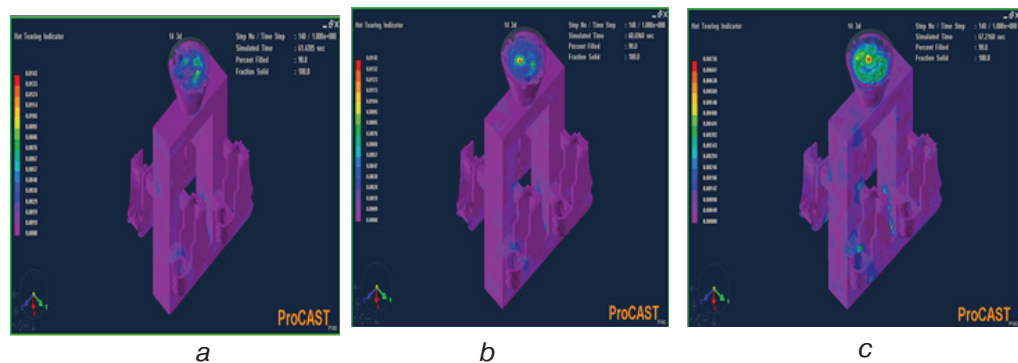


Figure 6. Shows the result for hot tearing in 14 mm gate (a); hot tear 3.9 % in pouring temperature of 1570 °C, (b); hot tearing 3.6 % at pouring temperature 1600 °C, (c); hot tearing 3.7 % in pouring temperature 1630 °C

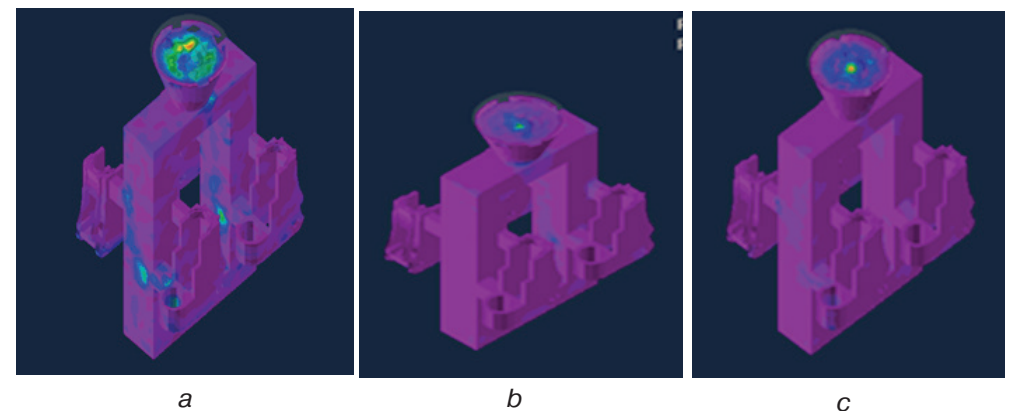


Figure 7. Shows result for hot tearing in 16 mm getting length, (a); hot tearing 4.2 % in pouring temperature 1570 °C, (b); hot tearing/crack 1.18 % in pouring temperature 1600 °C, (c); hot tearing/crack 4.7 % in pouring temperature 1630 °C

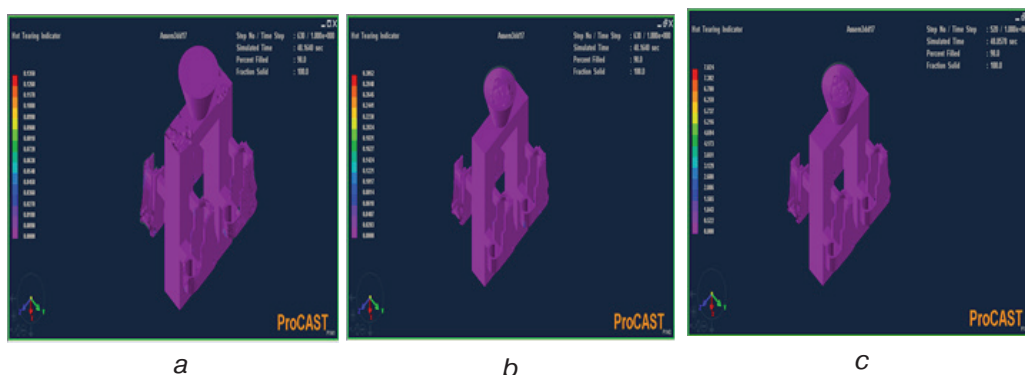


Figure 8. Result for hot tearing in 17 mm getting length a); hot tearing/crack 4.9 % at pouring temperature 1570 °C, (b); hot tearing/crack 3.6 % in pouring temperature 1600 °C, (c); hot tearing/crack 0 % (zero) in pouring temperature 1630 °C

1570 °C, 1600 °C and 1630 °C were simulated using ProCast software for recognize optimum parameter for the production of rear sight base component developed by investment casting process.

Result for getting length 14 mm with different temperature

By taking 14 mm getting length as constant and by changing the pouring temperature as 1570 °C, 1600 °C, and 1630 °C the simulation results shown below for each the temperature

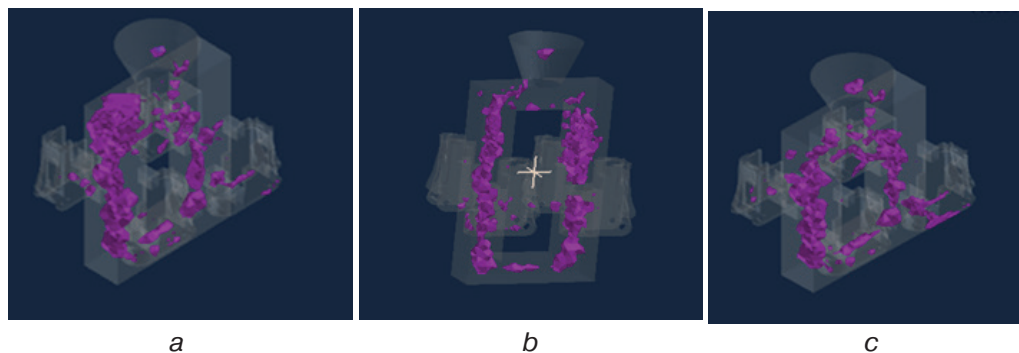


Figure 9. Result for shrinkage porosity in 14 mm getting length, (a); shrinkage porosity 1.53 % in pouring temperature 1570 °C, (b); shrinkage porosity 1.11 % in pouring temperature 1600 °C, (c); shrinkage porosity 1.4 % in pouring temperature 1630 °C

change. As shown in the result all they seem defect free because the purple color value is 0. But all the purple color had shrinkage porosity inside, so the value should determined according to the area which have purple color which have shrinkage porosity inside. In case those defects are visible in section view (refer in appendix), this is 3D view.

Results for getting length 16 mm with different temperature

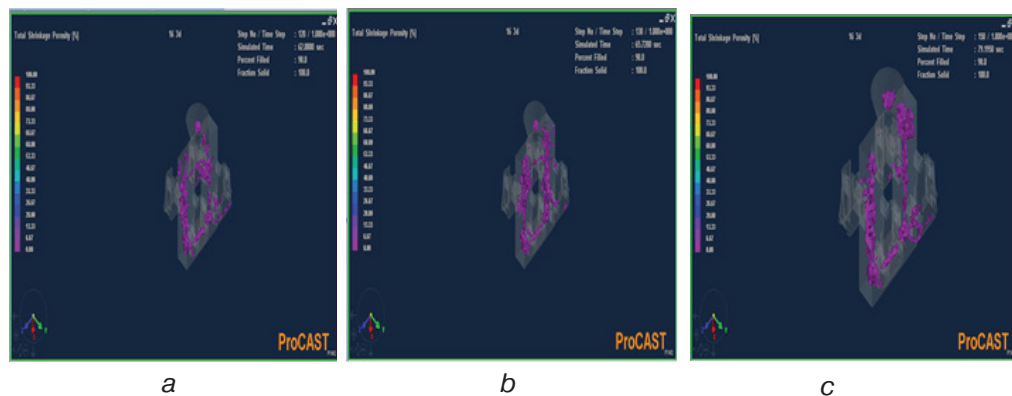


Figure 10. Result for shrinkage porosity in 16 mm getting length (a); shrinkage porosity 59.72 % in pouring temperature 1570 °C, (b); shrinkage porosity 53.91 % in pouring temperature 1600 °C, (c); shrinkage porosity 57.1 % in pouring temperature 1630 °C

Result of getting length 17 with different temperature

When getting length become optimum for the flow of molten metal the stress is minimum in casting product. Hot tearing as well as the shrinkage porosity had minimum due to the increment of shrinkage tolerance and the decrements of viscosity of the molten metal.

DISCUSSION

ProCast analysis result of different getting length on shrinkage porosity.

This study helps to investigate how getting length and pouring temperature matters in the casting products for developing with or without shrinkage porosity/hot tearing defects. In this section effects of getting length in product were discussed according to the results shown below.

The scatter graph shows figure the effects of pouring temperature in different gate length all the given levels increases in 15 mm (actual one) and 16 mm gate length in other hand in 14 and 17 mm the shrinkage porosity ware minimum.

At gate length of 16 mm investigated high shrinkage porosity and at 14 and 17 mm gate length shrinkage porosity is something near results were showed in all analytical data. The relation of gate length and pouring temperature is fluctuated. But when the pouring temperature is 1580 °C and 1600 °C shrinkage is very high and when in the given

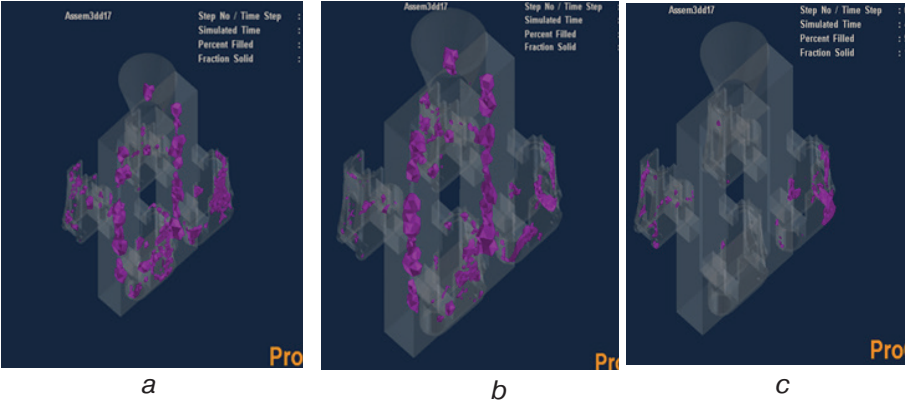


Figure 11. Result for shrinkage porosity in 17mm getting length (a); shrinkage porosity 2.007 % in pouring temperature 1570 °C, (b); shrinkage porosity 1.663 % in pouring temperature 1600 °C, c); shrinkage porosity 0.699 % in pouring temperature 1630 °C

gate length the pouring temperature is at maximum level of the given limit of the material type shrinkage porosity is goes to decrease. From the above result 17 mm gate length with 1630 °C pouring temperature is the optimum value.

ProCast analysis result of different gate length on hot tearing/ crack

In this section the relation of gate length and pouring temperature in casting products was analyzed using ProCast simulation software. Hot tearing is measured for each of the simulation according to the input data.

Table 1. Result of shrinkage porosity (the result is the total defect percentage per area) in 14, 16, 17 mm gating length

Gate length	Shrinkage porosity (%) PT = 1570 °C	Shrinkage porosity (%) PT = 1600 °C	Shrinkage porosity (%) PT = 1630 °C
14	1.539	1.43	1.11
16	59.7	57.19	53.91
17	2.007	0.699	1.66

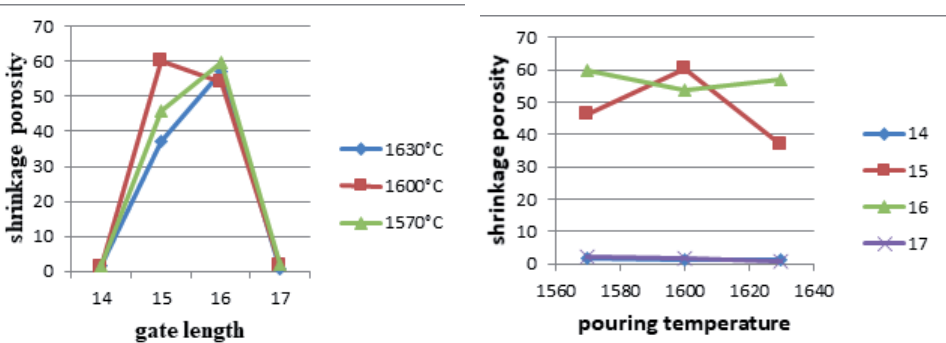


Figure 12. Scatter graph for effect of pouring temperature in shrinkage porosity defects; scatter graph for effect of gate length in shrinkage porosity

The scatter graph shows the effects gate length and pouring temperature in shrinkage porosity and hot tearing defects. 14, 15 (actual one), 16, and 17 mm gate length were plotted for understanding the influence in casting products.

When one of the parameter changed the results have been dynamically deferent and

Table 2. Result of hot tearing/crack (the result is the total defect percentage per area) in 14, 16,17 mm gating length

Gate length (1570 °C)	Hot tearing / crack (%) PT = 1570 °C	Hot tearing / crack (%) PT = 1600 °C	Hot tearing / crack (%) PT = 1630 °C
14	3.9	3.6	3.7
16	4.2	1.18	4.7
17	4.9	3.6	0

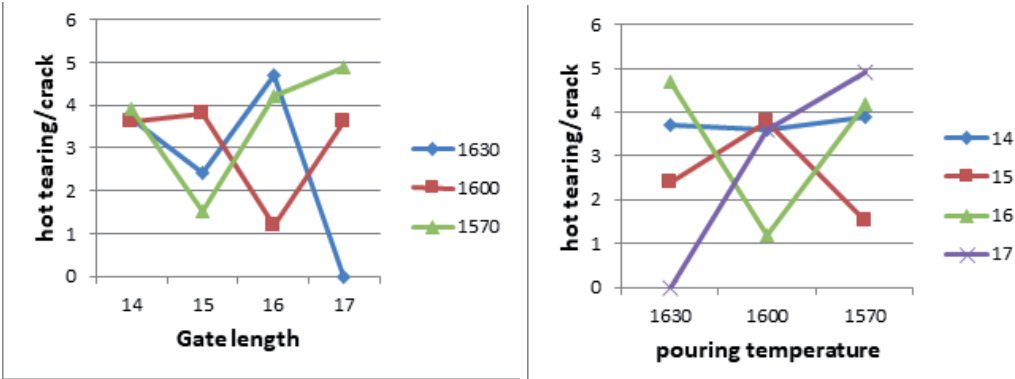


Figure 13. Scatter graph for effect of pouring temperature in hot tearing defects; scatter graph for effect of gate length 14, 15 (actual one), 16 and 17 mm in hot tearing defects

not constant. More of when temperature is above 1600 °C started to reduce hot tearing after solidification. And 17 mm of gate length and 1630 °C have been the optimum value of hot tear defects in rear sight base component which is manufactured by investment casting production process.

Comparison between Current Design and Optimized Design Using ProCAST Casting Simulation Software

From the analysis optimum pouring temperature and gate length were observed in order to manufacture rear sight base using investment casting process with minimum rejection. The currently used process parameters are results high rejection due to different defects. In this section the current design and the optimum designs were compared using ProCAST simulation. The comparison ware may help to allow the result which is obtained in this research due to the current one has defected in both NDT testing result and in simulation result.

Table 3. The comparison results between the initial design and the optimized design

Component	Gate length (mm)	Pouring temperature (°C)	Shrinkage porosity (%)	Hot tearing / crack (%)	Deference
Former design	15	1580	50.33	9.4	Sp = 40.93
Optimized design	17	1630	0.699	0	Ht = 9.4



Figure 14. Result of hot tearing of 15 mm gate length with in 1580 °C pouring temperature; result of hot tearing of 17 mm gate length with in 1630 °C pouring temperature

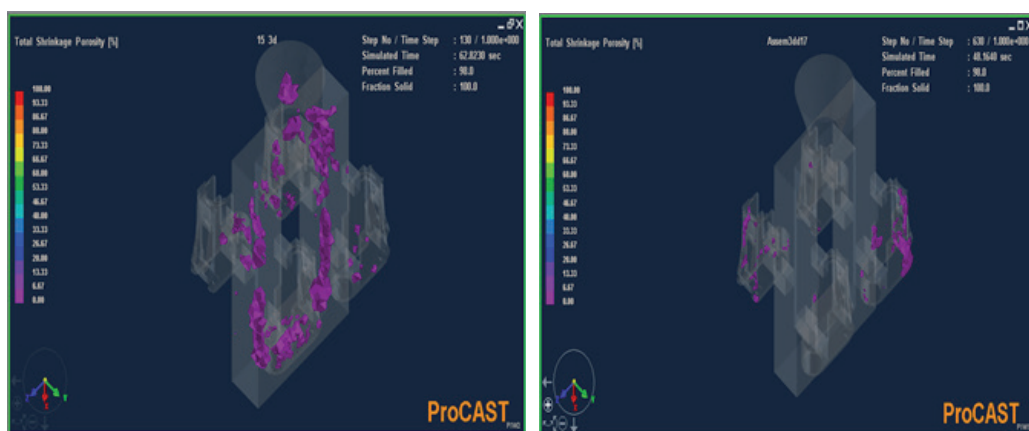


Figure 15. Results of shrinkage porosity on 15 mm gate length with in 1580 °C pouring temperature, Results of shrinkage porosity on 17 mm gate length with in 1630 °C pouring temperature

The current design had getting length of 15 mm and pouring temperature is 1580 °C. 50.33 % of the product had shrinkage porosity defects and 9.4 % had hot tearing / crack these results high rejection of the component during production period. Depend on the analytical method the optimum value for the production of rear sight base component developed by investment casting is 17 mm getting length and 1630 °C which have only 0.699 % shrinkage porosity and 0 % hot tearing. Depends on the recent literature the result which obtained in this research is closer to the experimental result.

CONCLUSION

In this paper, defect formation of Rear sight base component of AK47 developed by investment casting process was investigated. Investigation of cause of defects formation in rear sight base part has been done by using interview/discussion/group discussion and NDT Method. From those investigations high percentage defect and influential parameters were selected based on cause-effect diagram. Optimization of process parameter such as getting length and pouring temperature were analyzed using commercially available software package ProCast. The rear sight base model was created by SOLIDWORKS software and imported in to ProCast software. Finite element analysis using ProCast and analytical methods are done. FE model of rear sight base geometry is meshed with tetrahedral element. Mesh refinement are done on different getting length and pouring temperature, so for those each geometry mesh elements done casting and solidification process using casting software. The comparison results of all different getting length

and pouring temperature showed the effect of the two parameters on the formation of hot tear/ crack and shrinkage porosity and helps to select the optimum results.

Optimization of getting length resulted in 0 % of hot tear and 0.669 % of shrinkage porosity in 17 mm getting length. In getting length of 17 mm and optimized pouring temperature of 1630 °C, shrinkage porosity is reduced by 40.93 % and hot tearing/crack is reduced by 9.4 % from the initial scheme. Finally, the comparison have been done between the original product and optimized one by using ProCast software package.

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ДОСЛІДЖЕННЯ ТА ОПТИМІЗАЦІЯ ДЕФЕКТІВ ЛИТТЯ ПІДСТАВКИ ПРИЦІЛЬНОЇ ПЛАНКИ АК47 ПРИ ЛИТТІ ПО МОДЕЛЯМ, ЩО ВИТОПЛЮЮТЬСЯ

Процес лиття за моделями, що витоплюються, – це метод виробництва багатьох важливих компонентів і деталей, які мають багато промислових і комерційних застосувань. Сьогодні всі високоточні компоненти медичної, оборонної, автомобільної та інших галузей промисловості виробляються за допомогою цього процесу. При литті даним способом можуть виникати різні дефекти, такі як: тріщини, пористість, гарячий розрив, усадка, усадка тощо. Це відбувається через погану конструкцію литників та стояку, а також неправильного вибору технологічних параметрів процесу. Відливання підставки прицільної планки є складним завданням через складну геометрію та наявність тонких стінок. Для таких компонентів зі складною геометрією такі дефекти, як гарячий розрив, усадкова пористість тощо, є поширеними і потребують вирішення. Причини їх виникнення досліджено за допомогою дослідного спостереження, групового обговорення та неруйнівного тестування. З досліджень було вибрано високий відсоток дефектів і впливові параметри на основі методу причинно-наслідкових діаграм. Оптимізація параметрів процесу, таких як заповнюваність форми та температури заливки, проаналізовано за допомогою програмного забезпечення ProCast. Моделювання містить аналіз методом скінченних елементів, моделювання течії рідини та затвердіння металу за різної температури заливки та розмірів литникової системи для прогнозування усадкової пористості та імовірності утворення гарячих тріщин. З результату моделювання підібрано оптимальну температуру заливки і розмірів литникової системи. Для оптимізованої довжини 17 мм спостерігалось 0 % дефектів гарячого розриву та 0,669 % дефектів усадкової пористості. Оптимізована температура заливки становила 1630 °C для виробництва базових компонентів задньої частини деталі обраним способом лиття. Для отримання довжини 17 мм з оптимізованою температурою заливки, усадочну пористість було зменшено на 40,93 %, а гарячі тріщини зменшено на 9,4 %, порівняно з попередньою схемою (температура заливки 1580 °C, довжина живильника 15 мм).

Ключові слова: лиття по моделям, що витоплюються, програмне забезпечення ProCast, дефекти, підставка прицільної планки.