논 문

Evaluation on Casting Material Characteristics of Aluminum Alloy and Mild Steel for Tire Mold Manufacturing by Casting Method

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Abstract

본 연구에서는 유한요소법을 적용한 수치해석을 이용하여 타이어 제조용 금형을 생산하기 위해 사용되는 주조재의 열적 특성에 관하여 조사해 보았다. 고 품질의 정밀도가 좋은 타이어를 제조하기 위해, 일반적으로 타이어 제조용 금형의 주조재로 많이 사용되고 있는 알루미늄 합금과 비교 대상으로 연강을 선정하여 각각의 주조재에 대한 응고과정에서의 온도분포와 응력분포 결과를 수치적으로 계산해 보고 결과를 예측해 보았다. 수치해석을 통한 결과에서, 알루미늄 합금을 사용한 금형의 냉각과정 동안의 온도분포는 연강에 비해 보다 더 안정적으로 나타나는 것을 확인하였으며, 응력분포 결과 또한 알루미늄 합금 금형이 연강에 비해 정밀도를 향상시키고 좋은 품질의 제품을 얻는 데 보다 나은 것으로 나타났다.

그리고 금형의 온도분포와 응력분포는 금형의 냉각과정 동안 주조재의 초기 냉각온도에 의해 크게 영향을 받는 것으로 사료된다. 마지막으로, 이러한 수치해석에 의한 금형의 열적 특성 예측은 향후 고품질, 고정밀도의 금형 생산을 위한 예비성능평가 방법과 경제적 측면에서 매우 유용하게 활용할 수 있을 것으로 보인다.

Key words : Finite Element Method, Aluminum alloy, Mild Steel, Casting Mold, Thermal Stress.

(Received July 21, 2008 ; Accepted August 26, 2008)

1. Introduction

It is a modern trend that casting products are made highly functional and precise, and the competitiveness of the final products depends on the design technology for the casting process and the temperature profile of the casting [1].

In order to mass-product high value-added and precise products, die casting or low pressure die casting method is used. In the casting process, it is also very important for estimating the metal structure and quality of the end products to know the change of temperature by the time [2].

In addition, when the casting is cooled, the temperature profile of the casting and the growth rate of the solidification interface play a very important role in determining fine structure and mechanical and physical properties of the casting. And, it is necessary to accurately understand the heat transfer characteristic at the casting mold interface in order to predict and control these temperature profile and solidification interface growth rate.

So, many researches for this have been reported in the literature. Vijayaram et al., investigated the numerical simulation of casting solidification in permanent metallic molds [3]. Also, numerical simulation of filling and solidification of permanent mold casting was investigated by Shepel et al [4]. Moreover, since the 1990s, the mold material has been substituted from general mild steel to aluminum alloy to improve the quality of the casting mold. However, a general structure has not yet been established to accurately measure the amount of shrinkage and the size change by predicting the temperature profile by the time while the mold is solidified. Therefore, in the present study, sectional mold which consisted of 8 pieces with the same shape is selected as an analysis model because it is usually used to the manufacturing industry of tire mold. To investigate the evaluation on casting material characteristics of aluminum alloy and mild steel during casting process, is used numerical analysis for applying a finite element method. Especially, temperature and stress distributions inside the aluminum alloy and mild steel is calculated by numerical method and thermal characteristics of aluminum alloy compared with those of mild steel, respectively.

2. Numerical Analysis

In the present study, the commercial code "COMSOL Multiphysics ver 3.3" applying a finite element method was

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used in order to predict the temperature and the stress distribution inside the tire mold used aluminum alloy and mild steel. Also, numerical results of aluminum alloy were compared with those of mild steel to obtain the thermal characteristics of casting material.

For the numerical analysis, the physical properties of aluminum alloy and mild steel as shown in Table 1 are used. Figs. 1 and 2 display the analysis model using two materials of two-dimensional shape completed the mesh process and show the measurement points of temperature and stress, respectively. Analysis model was composed of the upper and lower part of molding sand, chilled steel, core and casting material. As shown in Table 2, for the numerical analysis, physical properties of casting, core and chilled steel was used molding sand, gypsum and SC42(Steel AISI 4340), respectively. The initial temperature condition of each part was set to be the pre-selected values as shown in Figs. 1 ~ 2. Also, the boundary condition was considered that contact surface of the molding sand, core and casting material was assumed to be the conduction state. The inside of each part except for the contact surface was assumed to be the convection state. However, in this study, the radiative heat transfer is not assumed because the problems of thermal-structural analysis such as casting material are governed the conduction and convection heat transfer.

Table 1. Physical properties of aluminum alloy and mild steel.

Properties	Unit	Value	
		Aluminum Alloy	Mild Steel
Thermal Conductivity	W/m・K	140	51.9
Young's Modulus	GPa	70	200
Poisson's Ratio	-	0.33	0.29
Density	kg/m^3	2,670	7,870
Specific Heat	kJ/kg・K	0.88	0.472
Thermal Expansion Coefficient	-	23.6×10^{-6}	12.6×10^{-6}

Table 2. Physical properties of gypsum (Core), SC42 (Steel AISI 4340) and molding sand.

Properties	Unit	Value		
		Gypsum	SC42	molding sand
Thermal Conductivity	W/m・K	0.1627	44.5	1.4
Young's Modulus	GPa	131	205	70
Poisson's Ratio	-	0.27	0.29	0.17
Density	kg/m^3	2,320	7,850	2,200
Specific Heat	kJ/kg・K	1.066	0.475	0.73
Thermal Expansion Coefficient	-	4.15×10^{-6}	12.3×10^{-6}	0.5×10^{-5}

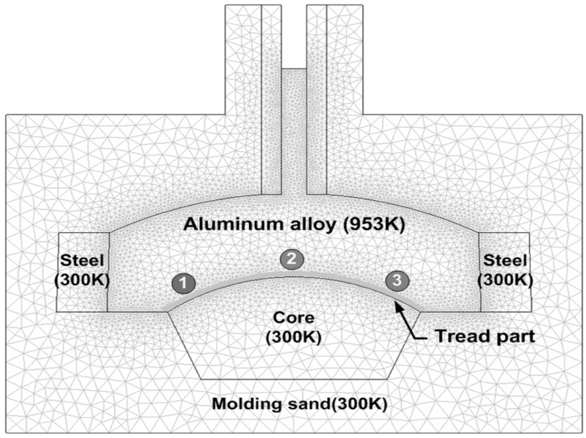

Fig. 1. Schematic diagram of analysis model using aluminum alloy.

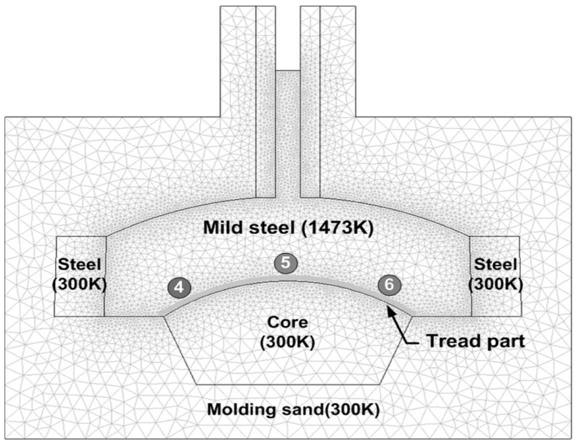

Fig. 2. Schematic diagram of analysis model using mild steel.

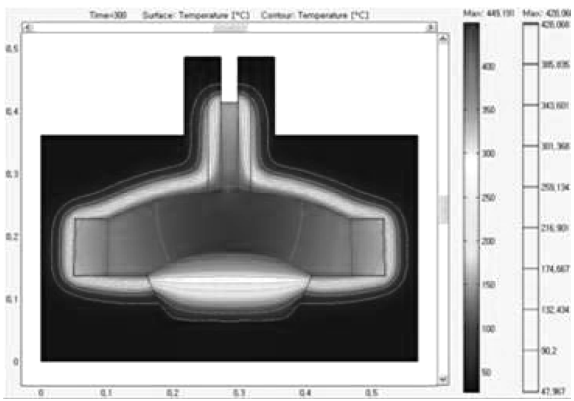

Fig. 3. Visualization of temperature distribution in aluminum alloy at 15 minutes.

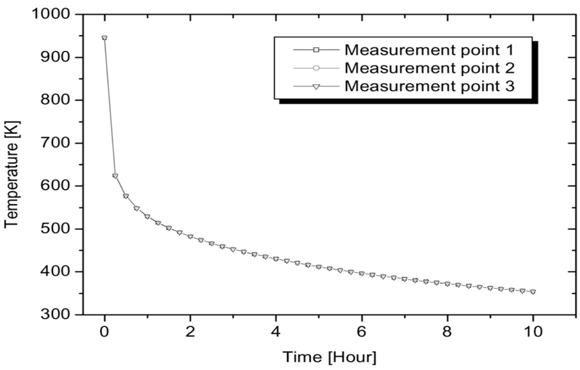

Fig. 4. Temperature variation in aluminum alloy at the measurement point during the cooling time, 10 hours.

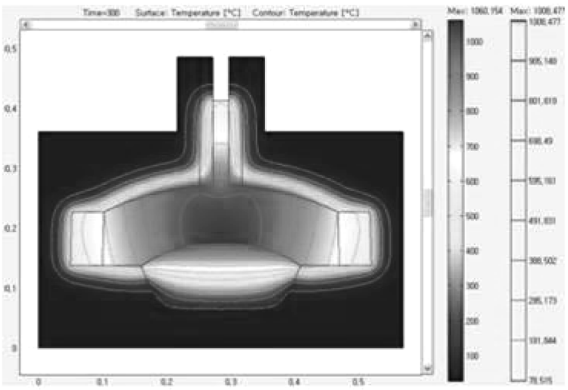

Fig. 5. Visualization of temperature distribution in mild steel at 15 minutes.

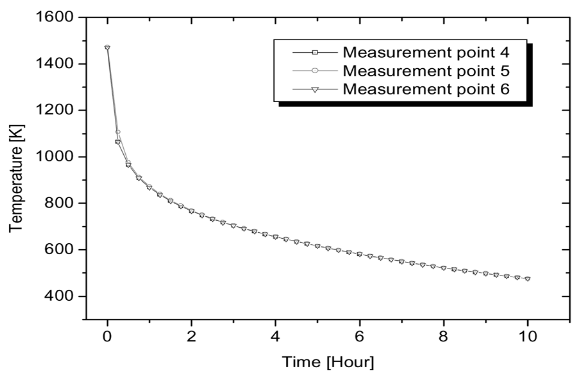

Fig. 6. Temperature variation in mild steel at the measurement point during the cooling time, 10 hours.

3. Results and Discussion

3.1 Temperature distribution

In this study, the initial temperature of aluminum alloy and mild steel is set up with approximately 953K and 1473K, respectively. It means that setting temperature is melting point of two materials and is injection temperature when the mold material is injected to the casting device. Also, as shown in Figs. 1 ~ 2, the measurement points of 1 ~ 3 and 4 ~ 6 on the tread part are selected by reason that tread part is closely related to the quality of mold for the automobile tire was manufactured.

Table 3. The temperature values of aluminum alloy and mild steel at each point.

Time [min]	Temperature [K]					
	Aluminum Alloy			Mild Steel		
	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
0	953	953	953	1,473	1,473	1,473
5	702.6	722.3	703.7	1,225.8	1,332.8	1,225.3
10	652.5	655.5	652.7	1,122.7	1,191.8	1,122.4
15	627	628.8	627.1	1,064.4	1,105.6	1,064.3
20	607.7	609.1	607.8	1,023	1,048.4	1,022.9
25	592	593	592.1	991.6	1,008.2	991.5
30	579	579.8	579.1	965	976	965

Figs. 3 ~ 6 show the result of temperature distributions inside the aluminum alloy and the mild steel by numerical method. Figs. 3 and 4 visually display the temperature distribution inside the aluminum alloy and mild steel at cooling time of 15 minutes. Also, Figs. 5 and 6 show the results of the temperature variation inside the casting materials during the cooling process extending from initial cooling time to 10 hours. When the results of temperature distributions of two materials were observed during the cooling process, it is revealed that the cooling time of the aluminum alloy is faster than mild steel. And, according to the results of temperature values by the measurement points during the cooling time at 30 minutes, aluminum alloy has more uniform temperature difference than mild steel as shown in Table 3. In addition, the temperature value at the measurement point 2 is larger than other points because the measurement points 1 and 3, where the chilled steel was contacted with the casting material surface, are occurred the rapid heat transfer. It means that cooling of casting material makes slow progress at the point 2 on the tread part.

3.2 Stress distribution

Generally, thermal strain inside the casting material occurred by the temperature difference during the cooling process. It is predicted that the stress occurred to the casting material by the temperature difference. The result of temperature variations is closely related to the precision and the quality of mold for automobile tire. In this study, stress distributions at the measurement points are calculated by numerical analysis from the results of temperature profiles.

Figs. 7 and 8 show the result of stress variations inside the aluminum alloy and mild steel at the measurement

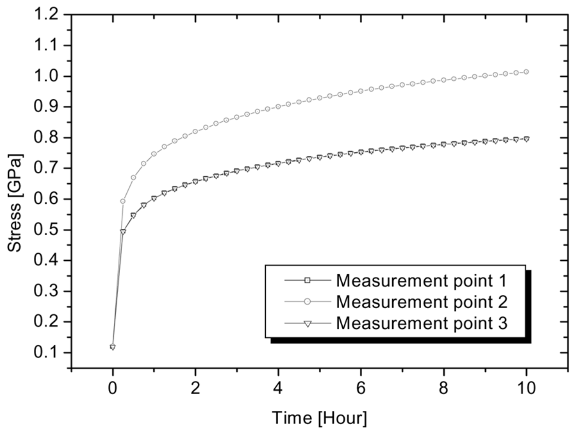

Fig. 7. Stress variation in aluminum alloy at the measurement point during the cooling time, 10 hours.

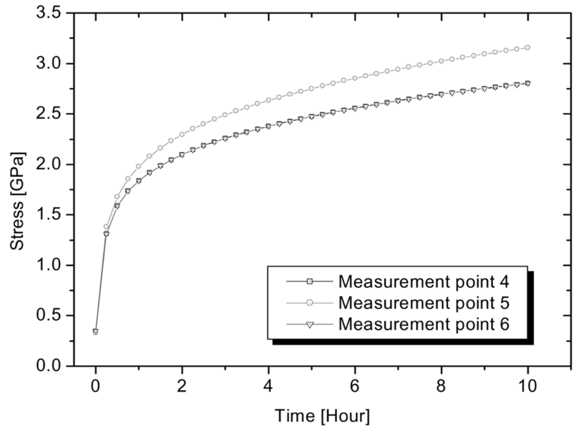

Fig. 8. Stress variation in mild steel at the measurement point during the cooling time, 10 hours.

Table 4. The maximum stress values of aluminum alloy and mild steel.

Material	Max. Value	Location
Aluminum Alloy	1.012 GPa	Point 2
Mild Steel	3.156 GPa	Point 5

points. Also, the result of maximum stress value and point during the cooling process is listed in Table 4, respectively. On the whole, the result of stress variations occurred that mild steel casting is larger than aluminum alloy as shown in Figs. 7 and 8. As to measurement points, the stress value of measurement points 2 and 5 is larger than other points 1, 3 and 4, 6 in case of aluminum alloy and mild steel, respectively.

4. Conclusions

Following conclusions can be drawn from the above results;

1) On the whole, the cooling time is revealed that aluminum alloy is faster than mild steel when the results of temperature distributions inside the casting material of aluminum alloy and mild steel during the cooling time.

2) According to the results of temperature values by the measurement points during the cooling time at 30 minutes, aluminum alloy has more uniform temperature distribution than in the case of mild steel.

3) In case of stress distributions, the result of stress variations occurred that mild steel is larger than aluminum alloy. Also, as to measurement points, the stress value at the point of middle center (i.e., point 2 and 5) is larger than other points 1, 3 and 4, 6 in case of aluminum alloy and mild steel, respectively.

4) In the end, the results of temperature and stress distributions are closely related to the temperature difference of casting material during the cooling process. Also, aluminum alloy casting is more effective and obtains the high quality of mold for the automobile tire was manufactured. Moreover, the introduced technique of numerical method is very useful and is important things to improve the precision in the casting industry.

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