Casting Simulation Analyses of A390 Aluminum Brake Shoe

謝楷模、胡瑞峰

E-mail: 9419529@mail.dyu.edu.tw

ABSTRACT

The A356 aluminium alloy was used on the casting of the brake shoe in the near years, but, the braking action was apt to cause the brake shoe to increase its body size because of its higher thermal expansion character of A356 alloy. The phenomenon would induce the brake lining to contact the brake drum abnormally and to decrease the braking efficiency. The A390 aluminium alloy with low coefficient of expansion can then be used to cast the brake shoe and thus to solve this problem. This research is aimed at evaluating how to cast the A390 aluminum alloy brake shoe by the CO2 sand mold method, utilizing the computer-aided engineering (CAE) simulation software FLOW-3D to study the influences of gating system designs on the A390 alloy brake shoe, and to analyze the flow of filling and the solidification of brake shoe castings. In addition, the simulations are also conducted and expected to achieve the optimum design of gating and riser systems for the A390 alloy brake shoe, and the X-ray examinations for the practical castings poured are carried out to evaluate the validity of FLOW-3D simulations. The criteria of predicting the defects produced in castings which are built in the software FLOW-3D, including the solidification fraction, solidification time, solidification gradient, solidus velocity and Niyama porosity index were used to determine the gating system designs, and to find the position of the shrinkage in the brake shoe castings. The results of this study indicate that the gating system with design of the sprue well can alleviate the flowing impact of aluminum melt falling from the inlet of sprue to the runner. While the design of bilateral R corners joining the runner and the ingate can reduce the flowing velocity at the ingate. Besides, the non-pressurized gating system with 1:4:4 gating ratio can effectively control the velocity at the ingate and prevent the turbulence of melt flow compared to the other gating systems with gating ratio(1:2:2, 1:2:3 and 1:3:3). The practical castings show that the shrinkage defects occurred are in accordance with the results of simulation. Finally, the casting designs by the FLOW-3D would improve the quality of A390 alloy brake shoe castings.

Keywords : FLOW-3D ; brake shoe ; A390 aluminum alloy ; CO2 sand mold ; CAE ; computer-aided engineering

Table of Contents

第一章 前言..... 1 第二章 文獻探討..... 3 2.1 鑄造用鋁合金..... 3 2.1.1 A390鋁合金..... 4 2.1.2 鋁合金凝固模式..... 4 2.2 縮孔之形成..... 5 2.3 鼓式煞車蹄片..... 6 2.4 澆流道系統..... 7 2.4.1 澆口比設計..... 8 2.4.2 澆盆..... 9 2.4.3 豎澆道..... 9 2.4.4 橫流道..... 11 2.4.5 進模口..... 12 2.4.6 冒口..... 12 2.5 CO2砂模法..... 15 2.6 鑄造電腦模擬模擬分析..... 15 2.6.1 電腦輔助方案設計和熱參數影響..... 16 2.6.2 電腦模擬分析技術..... 17 2.6.3 FLOW-3D特殊模擬技巧..... 18 2.6.4 FLOW-3D初始條件設定..... 21 第三章 實驗方法與步驟..... 28 3.1 實驗目的..... 28 3.2 鑄造方案設計..... 28 3.3 實驗方法..... 29 3.3.1 電腦輔助設計鑄件模型..... 29 3.3.2 建立分析網格..... 29 3.3.3 熱物性質及邊界條件設定..... 30 3.3.4 模擬分析之進行..... 31 3.3.4.1 流動充填模擬..... 31 3.3.4.2 凝固熱傳模擬..... 31 3.4 實際鑄件澆鑄..... 32 3.4.1 X-ray檢驗..... 32 3.4.2 模擬結果與實際鑄件比較..... 32 第四章 結果與討論..... 46 4.1 流動充填模擬分析..... 46 4.1.1 A1方案-不具豎澆道井之澆口比1:2:2直角澆流道系統..... 46 4.1.2 A2方案-具豎澆道井之澆口比1:2:2直角澆流道系統..... 48 4.1.3 具單邊R角之澆口比1:2:2澆流道系統..... 50 4.1.4 A6方案-具雙邊R角(0.75Wr)之澆口比1:2:2

澆流道系統.... 50 4.1.5 A7方案-具雙邊R角(0.75Wr)之澆口比1:2:3澆流道系統.... 50 4.1.6 A8方案-具雙邊R角(0.75Wr)之澆口比1:3:3澆流道系統.... 51 4.1.7 A9方案-具雙邊R角(0.75Wr)之澆口比1:4:4澆流道系統.... 51 4.1.8 A10方案-具45°斜置進模口之澆口比1:2:2澆流道系統..... 52 4.1.9 A11方案-具雙流路之澆口比1:2:2澆流道系統..... 52 4.1.10 A12方案-澆口比1:4:4之澆冒口系統..... 53 4.2 凝固熱傳模擬分析..... 53 4.2.1 固相分率指標..... 54 4.2.2 凝固時間指標..... 54 4.2.3 溫度梯度指標..... 55 4.2.4 固液界面速度指標..... 56 4.2.5 Niyama孔洞指標..... 56 4.3 煞車蹄片之X-ray檢驗..... 57 第五章 結論..... 103 參考文獻..... 105

REFERENCES

[1] 胡瑞峰, 鋁-矽(鎂)系合金及鋁-矽-銅系合金流動性之研究, 國立台灣大學機械工程研究所碩士論文, (1997) [2] M. Dash and M. Makhlouf, “ Effect of Key Alloying Elements on the Feeding Characteristics of Aluminum – Silicon Casting Alloys ”, Journal of Light Metals 1, pp. 251-265. (2001) [3] D. L. Zalensas, Aluminum Casting Technology, AFS, Inc. Des Plaines, Illinois. (1993) [4] J. E. Hatch, Aluminum Properties and Physical Metallurgy, American Society for Metals, Metals Park, Ohio, pp. 200-247. (1984) [5] J. L. Jorstad, “ The Hypereutectic Aluminum-Silicon Alloys 390 and A390 ”, Trans. of the Metallurgical Society of AIME, Vol. 242, pp. 1217-1221. (1968) [6] J. L. Jorstad, “ Applications of 390 Alloy:An Update ”, AFS Transactions, Vol. 92, pp. 573-578. (1984) [7] P. Kapranos, D. H. Kirkwood, H. V. Atkinson, J. T. Rheinlander, J. J. Bentzen, P. T. Toft, C. P. Debel, G. Laslaz, L. Maenner, S. Blais, J. M. Rodriguez-Ibabe, L. Lasa, P. Giordano, G. Chiarmetta and A. Giese, “ Thixoforming of an Automotive Part in A390 Hypereutectic Al – Si Alloy ”, Journal of Materials Processing Technology 135 , pp. 271-277. (2003) [8] 莊裕仁, 凝固速率對A390鋁合金矽形態與硬度影響之研究, 國立台灣師範大學工業教育研究所碩士論文, (2000) [9] J. Campbell, Solidification Shrinkage, CASTINGS, pp. 192-194. (1969) [10] T. S. Piwonka and M. C. Flemings, “ Pore Formation in Solidification ”, AFS Transactions, Vol. 236, pp. 65-157. (1966) [11] Q. T. Fang and D. A. Granger, “ Porosity Formation in Modified and Unmodified A356 Alloy Castings ”, AFS Transaction, Vol. 97, p 989. (1989) [12] G. K. Sigworth and C. Wang, “ Mechanisms of Porosity Formation during Solidification:A Theoretical Analysis ”, Metal. Trans. B, Vol. 24, p 349. (1993) [13] 蕭瑞聖, 機車原理與機構, 徐氏基金會, pp. 218-220, (1990) [14] Rudolf Limpert, Brake Desigh and Safe, Society of Automotive Engineers. Inc. (1999) [15] A. J. Day, “ An Analysis of Speed, Temperature, and Performance Characteristiscs of Automotive Drum Brakes ”, Journal of Tribology, Vol. 110, pp. 298-305. (1988) [16] A. J. Day, “ A Finite Element Approach to Drum Brake Analysis, ” Proc. of the Institution of Mechanical Engineers, Vol. 193, pp. 401-407. (1979) [17] C. Jordan, J. L. Hill and T. S. Piwonka, “ Computer Designed Gating System:Promises and Problems ”, AFS Transactions, Vol. 96, pp. 603-610. (1988) [18] 賴耿陽, 非鐵合金鑄物, 復漢出版社有限公司出版, (1999) [19] W. S. Hwang and R. A. Stoehr, “ Modeling of Fluid Flow ”, ASM Metals Handbook, 9th edition, Vol. 15, Chapter 11, Section, B, pp. 867~876. (1988) [20] J. F. Wallace, E. B. Evans, “ Gating of Gray Iron Casting ”, AFS Trans, Vol. 65, pp. 267-275. (1957) [21] E. Bjorklund, “ Calculating Ingate Dimension for Gray Iron Casting ”, AFS Trans, Vol. 70, pp. 193-205. (1962) [22] 林振泰, 鑄鐵件澆冒口設計, 中華民國鑄造學會, pp. 120-183. (1972) [23] 楊惠春, 鑄造學, 五洲出版社, (1984) [24] 吳英豪, (新)鑄造學, 復文書局, pp. 147-148, (1993) [25] J. F. Wallace and E. B. Evans, “ Principles of Gating ”, Foundry, Vol. 87, p 74. (1959) [26] N. Wukovich and G. Metevelis, “ Gating: The Foundryman ’ s Dilemma, or Fifty Years of Data and Still Asking How? ”, AFS Transactions, Vol. 95, pp. 377-384. (1987) [27] J. Runyoro, S. M. A. Boutorabi and J. Compbell, “ Critical Gate Velocities for Film-Forming Casting Alloys:A Basis for Process Specification ”, AFS Transactions, Vol. 37, pp. 225-234. (1992) [28] Casting Process Design Guidelinesr, AFS Transactions, p. 869. (1997) [29] 陳查宗, 流路設計及流體充填現象之研究, 國立中央大學, (1996) [30] K. Grube and L. W. Eastwood, “ A Study of the Principles of Gating ”, AFS Transactions, Vol. 58, pp. 76-107. (1950) [31] J. F. Wallace and M. C. Fleming, Solidification Processing, McGraw-Hill, New York, p. 12 and pp. 54-146. (1966) [32] C. Beckermann, “ Development of New Feeding Distance Rules Using Casting Simulation: Part I. Methodology ”, Metallurgical and Materials Transactions B, pp. 731-740. (2002) [33] K. D. Carlson, S. Ou, R. A. Hardin and C. Beckermann, “ Development of New Feeding Distance Rules Using Casting Simulation: Part II. The New Rules ”, Metallurgical and Materials Transactions B, pp. 741-753. (2002) [34] ASM Metals Handbook, Casting, Vol. 15, 19th ed. pp. 577-580. (1977) [35] J. F. Wallace, Risering of Casting, Foundry, Vol. 87, p. 74. (1959) [36] J. B. Caine, “ Riser Casting ”, AFS Transactions, Vol. 57, p. 66. (1964) [37] L. Estrin, “ A Deeper Look at Casting Solidification Software ”, Modern Casting, Vol. 84, No.7, pp. 20-23. (1994) [38] 林惠娟、黃振東、鄭憲清, 鑄造程式之電腦模擬ProCAST應用實例介紹, 鑄造月刊77期, (1996) [39] S. Yue, G. Wang, F. Yin, Y. Wang and J. Yang, “ Application of an Integrated CAD/CAE/CAM System for Die Casting Die ”, Journal of Materials Processing Technology 139, pp. 456-468. (2003) [40] Q. X. Pei, T. S. Bai and P. C. Liu, “ Riserless Design of Ductile Iron Casting by Computer Program ”, AFS Transactions, Vol. 132, pp. 443-450. (1987) [41] A. S. Sabau and Viswanathan, “ Microporosity Prediction in Aluminum Alloy Castings ”, Metallurgical and Materials Transactions B:, Vol. 33, No 2, pp. 243-255. (2002) [42] W. H. Johnson and J. G. Kura, “ Some Principles for Producing Sound Al-7Mg Alloy Castings ”, AFS Transactions, Vol. 67, p. 535. (1959) [43] R. A. Entwistle, J. E. Gruzlesi and P. M. Thomas, “ Development of Porosity in Aluminum Base Alloys ”, AFS Transactions, Vol. 85, p. 345. (1977) [44] H. Huang and J. T. Berry, “ Evaluation of Criteria Function to Minimize Microporosity Formation in Long-Freezing Range Alloys, ” AFS Transactions, Vol. 101, p. 669. (1994) [45] G. V. Kutumba Rao and V. Panchanathan, “ End Chills Influence on Solidification Soundness of

Al-Cu-Si(LM4) Alloy Castings ”, AFS Transactions, Vol. 81, p. 110. (1973) [46] V. de L. Davies, “ Feeding Range Determination by Numerically Computed Heat Conduction ”, AFS Cast Metals Research Journal, p. 33. (1975) [47] Y. W. Lee, E. Chang and C. F. Chlue, “ The Role of Solidus Velocity in the Feeding Behaviour of Al-7Si-0.3Mg Alloy Plate Castings ”, Materials Science and Engineering, p. 233. (1990) [48] E. Niyama, T. Uchida, M. Morikawa and S. Saito, “ A Method of Shrikage Prediction and Its Application to Steel Casting Practice ”, 49th International Foundry Congress, p. 1. (1982) [49] H. M. Si, C. Cho and S. Y. Kwahk, “ A Hybrid Method for Casting Process Simulation by Combining FDM and FEM with An Efficient Data Conversion Algorithm ”, Journal of Materials Processing Technology 133, pp. 311-321. (2003) [50] M.R. Barkhudarov and C.W. Hirt, “ Casting Simulation: Mold Filling and Solidification-benchmark Calculations Using FLOW-3D ”, Modeling of Casting, Welding and Advanced Solidification Process VII, The Minerals, Metals & Materials Society, pp. 935-946. (1995) [51] W.S. Hwang and A. Stoehr, “ Computer Simulation for the Filling of Castings ”, AFS Transactions, Vol. 95, pp. 87-141. (1987) [52] FLOW-3D User ’ s Manual, Lecture 2: Hands On Session, Flow Science Inc. (2004)