DEVELOPMENT OF NOVEL HOT STAMPING TECHNOLOGY PROCESS OF TITANIUM ALLOY

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1. Introduction

In order to meet fuel consumption targets for the aviation sector, increasing demands for low density and high strength materials were observed. In this specific sector, low strength structural components are commonly produced from aluminum alloys, and high strength structural components are made from titanium alloys [1]. The main problem during hot forming of complex-shaped components from titanium alloys is time, energy and cost intensive. The aircraft industry currently uses methods such as superplastic forming (SPF) [2], superplastic forming with diffusion bonding (SPF-DB) [3], hot stretch forming [4], creep forming [5], hot gas-pressure forming [6] or isothermal hot forming [7, 8] to produce complex-shaped structural components. However, these techniques usually require a very high temperature, slow strain rate and simultaneous heating of tools and sheet during the forming process. These characteristics gradually decrease productivity, and proportionally increase the cost of production. For example in conventional hot stamping using a furnace, the heating time of forming tools exceed the time of 2 h [9]. In order to increase the productivity of forming processes, new forming techniques such as the solution heat treatment, forming and in-die quenching [10], the Quick-plastic forming [11], and the hot stamping using rapid heating [9,12] have been developed. One promising solution to overcome low efficiency/high cost problem found in traditional techniques is using the hot stamping process to form complex-shaped components from sheet metal with cold dies, and rapidly quenching the workpiece in the dies simultaneously. The hot stamping process promises to reduce the tool wear commonly found in conventional hot forming processes and be an overall more efficient and economical process when compared to conventionally used isothermal hot forming techniques [9]. Traditional hot stamping processes have mainly focused on forming lightweight alloys, such as aluminium alloys and ultrahigh strength steels, for the automotive industry. However, few references can be found focusing on the hot stamping of titanium alloys. Recently, there has been an increased demand for titanium components in the aerospace industry due to their high strength to weight ratio, excellent temperature stability and corrosion resistance [13,14]. Therefore, there is a clear need to study the hot stamping of titanium alloys to achieve required mechanical performance whilst reducing manufacturing cost.

2. Results

A novel hot stamping process for titanium alloys using cold forming tools and a hot blank was studied in this work. Uniaxial tensile tests at temperatures ranging from 600 to 900 °C and strain rates ranging from 0.1 to 10 s^{-1} were conducted to investigate the formability of Ti6Al4V alloy. The microstructure and post-form properties of the material were monitored during tests to characterize the flow behaviour of investigated alloy. Hot stamping tests were performed in a wide temperature range to verify the feasibility of the novel process for the Ti6Al4V alloy. The formability of the material under isothermal conditions increased with the increasing temperature and decreasing strain rate. A satisfactory elongation ranging from 30% to 60% could be achieved at temperatures ranging from 750 to 900°C respectively. During testing at various temperatures, a different microstructure evolution mechanisms were observed. In the range from 600 to 700°C, the main mechanism was recovery; whereas from 750 to 950°C, the main mechanism was transformation and recrystallization. The hardness of the material after deformation first decreased with the temperature due to recovery at 750°C, and subsequently increased due to the phase transformation and recrystallization at 900°C. During the hot stamping tests, qualified parts could be formed successfully at heating temperatures ranging from 750 to 850°C. By using the proposed novel hot stamping technology, a wing stiffener component made of Ti6Al4V titanium alloy was formed.

Keywords: Titanium alloys; Hot stamping, Formability; Post-form strength

3. References

[1] M. Peters, J. Kumpfert, C. H. Ward, and C. Leyens, "Titanium alloys for aerospace applications," *Adv. Eng. Mater.*, vol. 5, no. 6, pp. 419–427, 2003.
[2] D. Serra, "SUPERPLASTIC FORMING APPLICATIONS ON AERO ENGINES . A REVIEW OF ITP MANUFACTURING PROCESSES AERO ENGINES . A REVIEW OF ITP," 2009.
[3] H. Yang, X. G. Fan, Z. C. Sun, L. G. Guo, and M. Zhan, "Recent developments in plastic forming technology of titanium alloys," *Sci. China Technol. Sci.*, vol. 54, no. 2, pp. 490–501, 2011.
[4] A. Astarita, E. Armentani, E. Ceretti, L. Giorleo, P. Mastrilli, V. Paradiso, F. Scherillo, A. Squillace, and C. Velotti, "Hot Stretch Forming of a Titanium Alloy Component for Aeronautic: Mechanical and Modeling," *Key Eng. Mater.*, vol. 554–557, no. January, pp. 647–656, 2013.
[5] T. Deng, D. Li, X. Li, P. Ding, and K. Zhao, "Hot stretch bending and creep forming of titanium alloy profile," *Procedia Eng.*, vol. 81, no. October, pp. 1792–1798, 2014.
[6] K. Wang, G. Liu, K. Huang, D. J. Politis, and L. Wang, "Effect of recrystallization on hot deformation mechanism of TA15 titanium alloy under uniaxial tension and biaxial gas bulging conditions," *Mater. Sci. Eng. A*, vol. 708, pp. 149–158, 2017.
[7] T. Raghu, I. Balasundar, and M. Sudhakara Rao, "Isothermal and near isothermal processing of titanium alloys," *Def. Sci. J.*, vol. 61, no. 1, pp. 72–80, 2011.
[8] A. G. Ermachenko, R. Y. Lutfullin, and R. R. Mulyukov, "Advanced technologies of processing titanium alloys and their applications in industry," *Rev. Adv. Mater. Sci.*, vol. 29, no. 1, pp. 68–82, 2011.
[9] Z. Hamedon, K. Mori, and T. Maeno, "Hot Stamping of Titanium Alloy Sheet Using Resistance," pp. 12–15, 2013.
[10] J. Liu, H. Gao, O. El Fakir, L. Wang, and J. Lin, "HFQ forming of AA6082 tailor welded blanks," *4th Int. Conf. New Form. Technol.*, vol. 5006, p. 6082, 2015.
[11] P. F. Bariani, S. Bruschi, A. Ghiotti, and F. Michieletto, "Hot stamping of AA5083 aluminium alloy sheets," *CIRP Ann. - Manuf. Technol.*, vol. 62, no. 1, pp. 251–254, 2013.
[12] T. Maeno, K. ichiro Mori, and R. Yachi, "Hot stamping of high-strength aluminium alloy aircraft parts using quick heating," *CIRP Ann. - Manuf. Technol.*, vol. 66, no. 1, pp. 269–272, 2017.