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Tool design for inner race cold forging with skew-type cross ball grooves

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ABSTRACT

The inner race of CV (Constant Velocity) joints with asymmetric six cross ball grooves is an important load-supporting automobile part that transmits torque between the transmission and a driven wheel. This metal component has conventionally been produced by a machining sequence that includes material removal. As an alternative, a cold forging procedure using a semi-closed die is presented. The proposed cold forging is composed of six longitudinally segmentalized cross-ball grooving dies, a die holder, and forging punches, which were chosen with consideration of their operation mechanisms. Process design and detailed tool design have been conducted. To ensure the appropriateness of the suggested process with respect to deformation behavior, a 3-dimensional finite element simulation including forging load prediction is carried out, and experimental investigations are also performed using SCr420H steel as the initial billet material. Unexpected fracture failure of the die occurred due to the asymmetric geometry of the segmentalized cross ball grooving die, in response to which modification of the die geometry was carried out based on the results from the structural integrity evaluation, thereafter, the inner race was appropriately produced using the modified die. The dimensional accuracy at three critical cross sections of the forged inner race is investigated and compared. It is shown that the proposed semi-closed die cold forging could be successfully applied to the production of the inner race with the six skew-type cross ball grooves, and achieved with the dimensional variation under about 2.0%.

1. Introduction

Cold forging technologies are well known to have valuable and practical advantages including short lead-time and fast processing intervals for each operation. Such processes are thus generally used to produce various forged parts and to meet production costs. However, Kim et al. (2008) have reported that there are also disadvantages regarding productivity for complicated shapes and low-forgeability billet materials, so Faraji et al. (2012) have emphasized that machining processes including material removal are often needed to satisfy product quality requirements and restraints of the cold forging sequence. This increases the quantity of the initial billet required, as well as the manufacturing costs, when the machining procedures are used to produce final products with the complicated three-dimensional configurations. Recently, demand for various forged components with the complex shape has been increasing consistently, but Lee et al. (2009) have claimed that the conventional forging and machining schemes have limitations in satisfying various requirements for achieving fast lead-time, low production cost, complexity of a desired shape, and so forth. So, Sagisaka et al. (2012) have studied on eco-friendly manufacturing with respect to lubricants for cold forging.

Most of the automobile industry is also conscious of the necessity of replacing these traditional machining processes for producing a large volume of forged parts with complicated dimensions. Krušič et al. (2011) have mentioned that the current issues for automakers and related industries include the reduction of the production costs, the improvement of productivity and forgeability. And Deng et al. (2011) have emphasized to be needed the development of environment-friendly manufacturing technology. Based on these issues, Kroib et al., 2013 have described that priority is given to strengthening core capabilities regarding process replacement, the reduction of the manufacturing costs, and the improvement of the yield percentage of materials. For example, Kang et al. (2008) have considered the cold forging process to replace the machining processes for a sleeve cam of automobile start motor, and Ku et al.

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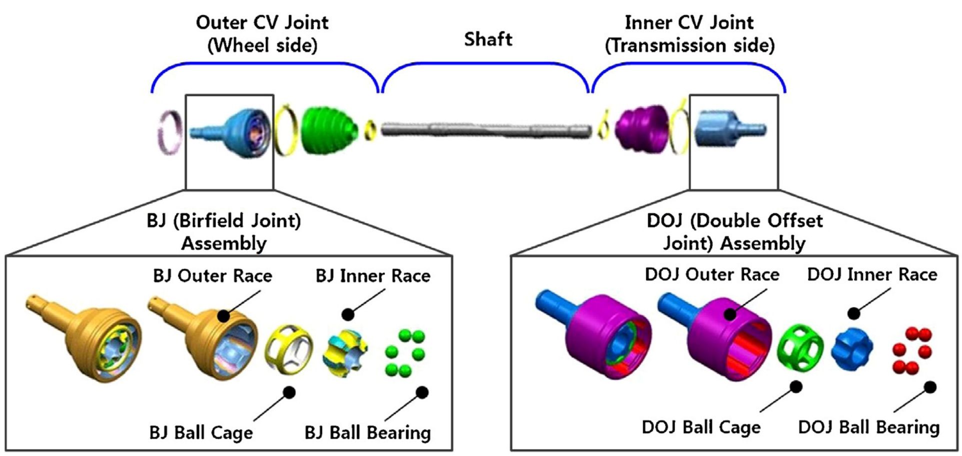
(2013a) have presented that the conventional multi-stage warm forging for manufacturing the outer race of CV joint could successfully be replaced with the multi-stage cold forging by the process simplification.

The conventional inner race of a CV (Constant Velocity) joint has parallel geometry with six ball grooves and ribs on the outer surfaces. Duarte and Martins (2004) have claimed that this component is an important load-supporting part of automobile, and transmits torque between the transmission and a driven wheel. And Park (2005) have mentioned that the inner race has generally been produced by the cold forging. However, Cao et al. (2011) have reported that unexpected kinematic behaviors such as gear shifting delay and gear shifting shock have occurred when the CV joint with the inner race is operated. To reduce the occurrence of such behaviors more effectively, inner races with six skew-type cross ball grooves have been recently introduced and applied in some vehicles. Because this inner race has been crossed with a skewed angle in each groove direction, its manufacturing process has a critical drawback related to limitations in ejecting the forged workpiece from the die cavity when using closed die and relevant tool sets. For this reason, the machining processes have been adopted to solve the weaknesses and interference between the forged workpiece and the tool structure. On the other hand, Zhu et al. (2013) have emphasized that there is a need to satisfy the aforementioned demands on manufacturing, as well as a desire for the extension of tool life. It means that the machining process to manufacture the



(a) Schematic views of CV joint

(b) Examples of forged inner race with ball groove

(c) Example of machined inner race with six skew-type cross ball grooves

Fig. 1. Schematic views of CV joint assembly and each component. (a) Schematic views of CV joint. (b) Examples of forged inner race with ball groove. (c) Example of machined inner race with six skew-type cross ball grooves.