貫通式ツール摩擦攪拌インクリメンタルフォーミングに関する研究

博 士 論 文 内 容 の 要 旨

専攻名 総合創成工学

分野名 物質加工学

氏　名 JIANG　WEI

１　論文題目（英文の場合は，和訳を付記すること）

Research on Penetrating Tool Friction Stir Incremental Forming

(貫通式ツール摩擦攪拌インクリメンタルフォーミングに関する研究)

２　要　　旨（和文 2,000 字程度又は英文 800 語程度にまとめること。）

Penetrating tool friction stir incremental forming (PTFSIF) is a variant of incremental forming developed for forming of concave-convex mixed shapes. PTFSIF combines single point incremental forming and bobbin tool friction stir welding. In PTFSIF, a penetrating tool can travel freely in the sheet metal without leaving any defects in the sheet. Thus, concave and convex shapes can be formed using the top and bottom tools, respectively. No specific machine or die are required in PTFSIF. However, the forming limit in height in PTFSIF is relatively small, less than 10 mm. The sheets fractured due to formation of groove-like defect at advancing side, that the tool rotation and feeding direction are the same. It had clarified that material flow from the advancing side to the retreating side causes the poor forming limit in height. For improving the forming limit in height, it is necessary to develop a method to avoid the formation of groove-like defect. The formation of groove-like defect and direction of material flow between advancing side and retreating side in PTFSIF were treated as two research directions in this thesis. This thesis consists of 6 chapters.

Chapter 1 presents the background of plastic working, introduction of manufacturing methods relevant to PTFSIF and the motivation of this thesis. The outline of this thesis was also included in it.

Chapter 2 presents the development of PTFSIF by combining incremental forming and bobbin tool friction stir welding. A separable penetrating tool was designed and manufactured for forming. The designed separable penetrating tool has the merits of an adjustable gap and replace-

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able probe. Friction stir welding with stir-in plate was conducted as preliminary experiment for finding the suitable working conditions. By the proposed PTFSIF, concave and convex shapes of 7 mm height/depth and a concave-convex mixed shape has 7 mm of depth and 7 mm of height were formed successfully. The sheets were fractured in PTFSIF due to formation of the groove-like defect, and the groove-like defect penetrates the sheets with the proceeding of forming. Material flow was also investigated and it was found that material flows from the advancing side to the retreating side. The groove-like defect was caused by this material flow.

In Chapter 3, forming conditions including pitch in radial direction, initial radius of forming cones and wall angle were changed to investigate these effects on the formation behavior of groove-like defect. The formation behavior of groove-like defect was estimated by the number of formed cycles before occurring groove-like defects. The larger the number of formed cycles before groove-like defects occurred is, the more difficult the groove-like defect occurred. From these results, it was found that groove-like defect occurred even in the condition of a wall angle of 90°. In those conditions the sheets were not formed into a 3D shape but the penetrating tool was useful for friction stir welding with stir-in plate in the sheet plane. The number of formed cycles before occurring groove-like defects increases with the increasing of the initial radius of formed cones.

Chapter 4 presents the relationship among the defects formation, tool temperature and revolutionary pitch in PTFSIF. Tool temperature was measured by a K type thermocouple which was embedded in the forming tool. Tool rotation and feed rates were changed for varying the revolutionary pitch. From the results, three kinds of defects, defect I, II and III, were classified by the fracture morphology. Defect II was the groove-like defect, and defect I and III were not groove-like defect, which the sheet fractured directly. The defect I has an irregular edge, caused by the low temperature. The defect III has a smooth and regular edge, caused by the high temperature. It was shown that the tool temperature of defect formation has a tendency of decreasing with increasing of revolutionary pitch. But the defect formation cannot be determined by only the tool temperature or the revolutionary pitch.

In Chapter 5, one-way tool paths and alternating tool paths strategies were used in PTFSIF. Forming limits in height with one-way tool paths and alternating tool paths were compared. The forming limit in height with alternating tool paths was approximately 30 mm and that with one-way tool paths was less than 10 mm. Volume change per unit length in radial direction for both formed sheets with alternating and one-way tool paths were calculated for examining the improvement of forming limit in height with alternating tool paths. The volume change per unit

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length observed with alternating tool paths was smaller than that with one-way tool paths, which means that a more uniform material distribution was achieved with alternating tool paths.

Finally, the concluding remarks for the present study and further prospects are given in Chapter 6.