Modelling of defects in ingot forging: with the finite element flow formulation

The present report presents an investigation of the ingot forging process with special emphasis on modelling the influence of die geometry on the soundness of the ingot after hot forging. An investigation on how to model damage is also performed. The influence of the lower die angle is quantified experimentally by utilizing downscaled lead model ingots (billets) being compressed by a tool with different lower die angles. Centreline defects, occurring due to the ingot casting processes, are modelled by drilling holes through the centreline of the cast billets. The experiments showed a marked influence on centreline hole closure by the lower die angle. Of the utilized lower die angles, a 120o lower die gives the largest hole closure when applying same press stroke for all the experiments. The performed experiments are compared with both 2D and 3D FEM simulations. Both simulations are found to mimic the experiments reasonably correct. Therefore both models are subsequently applied for further investigations of the influence of the lower die angle on the evolution of centreline defects. 2D FEM single stroke simulations of ingots having different hardening behaviours yielded an approximately constant lower die angle of 130o-140o giving rise to the largest centreline porosity closure regardless of material hardening behaviour applied. Friction was found only to have minor influence on the optimum. Multi stroke forging operations have also been modelled since the ingot forging process consists of many forging strokes. Two different approaches to quantify ductile damage is applied: uncoupled ductile damage or a porous plasticity model. Lower die angles ranging from 60o to 180o with 30o intervals are used in the simulations. It is found that when applying the uncoupled ductile damage criterion normalized Cockcroft & Latham, a lower die angle of 120o was found to be best. “Best” is evaluated using a primitive average of damage and effective plastic strain measures. When applying porous plasticity as a model for the description of damage, a 90o lower die angle is found to be best closely follow by the applied, larger lower die angles. A preliminary investigation of the influence of feed size is performed. Only two different lower die angles of 120o and 180o are utilized with either 400mm or 800mm feed. Damage is modelled with porous plasticity while at the same time also computing normalized Cockcroft & Latham damage. It is found that when evaluating damage only by relative density; feed size and lower die angle does not influence whether the hot forging process is successful or not. This is in disagreement with the general understanding of the ingot forging process. When evaluating ductile damage by the normalized Cockcroft & Latham criterion, marked differences is predicted depending on which lower die angle is applied. The damage is also affected by the feed size, indicating that the smallest of the two feed sizes should be utilized together with the 120o lower die in practice. These findings are in closer agreement with the general understanding of the ingot forging process. Therefore porous metal plasticity should not be used solely when evaluating the soundness of the final, forged ingot based on FEM simulations. Based on an analysis of forming fracture limit diagrams combined with uncoupled ductile damage criteria, it is found that the normalized Cockcroft & Latham criterion is most suited for modelling damage in bulk metal forming, if the forming fracture limit diagram can be described by a straight line having a slope of -1/2. A damage criterion independent of slope is presented. Often the forming fracture limit diagram consists of two straight lines intersecting one another in the principal strain space along a line corresponding to uniaxial tension. If the slopes of the two lines are -1/2 and -1, which is often encountered in practice, an uncoupled ductile damage criterion is introduced which predicts same damage value at fracture along both lines. A physical mechanism giving rise to different formability limits, depending on the applied stress state, is introduced. Further investigations of the mechanisms governing ductile fracture is still needed in order to confirm or reject the proposed damage criterion and damage mechanism.