SLM OF EXTRUSION DIES WITH LIQUID NITROGEN COOLING

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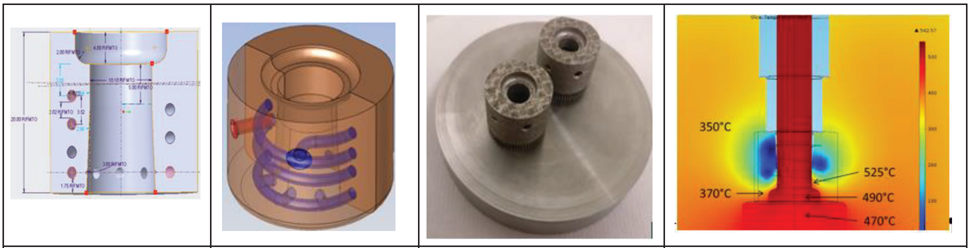
EXTENDED ABSTRACT

Temperature control during aluminium extrusion is a mandatory activity in order to produce defect-free profiles and to optimize process productivity [1]. During the extrusion process, the profile exit temperature increases due to amount of work spent to overcome friction and to plastically deform the workpiece that is converted to heat. In addition, if the ram speed or the extrusion ratio increase, the temperature further raises leading to detrimental surface defects such as hot cracks [1]. The main advantages of dissipate the excessive generated heat in the die and at the end of the forming zone are related to the possibility of increasing only slightly the extrusion force and to reduce the conduction path from the forming zone to the cooling source. In addition, it is possible to cool critical die areas directly by sizing and positioning cooling channels or cooling nozzles adequately to prevent hot cracking [1]. However, the manufacturing of conformal cooling channels close to the main forming zone by means of conventional machining is a difficult task for profiles and dies with highly complex geometries. Thus, the use of additive manufacturing technologies is a promising approach to allow a conformal cooling [1-2]. The chromium hot-work tool steels are the most widely selected materials for forging, die-casting and extrusion dies applications because of their high thermo-mechanical strength, fatigue strength, toughness and relative low cost [2]. Nowadays, thanks to the selective laser melting (SLM) technology, it is possible to produce structures with 99% density [2]. Since, to date, the additive manufacturing processes are often accompanied with higher manufacturing time and costs than conventional subtractive methods, a new concept for a hybrid extrusion die is presented [1-2].

In the present work, a multi-die is proposed in which the expensive AM part, the insert with conformal cooling channels, is integrated into a conventional machined steel housing. A profile produced with a short die lifetime and critical issues on thermal field has been identified and selected consisting in a round bar of 10mm diameter made by AA6060. A helicoidally channel has been designed to obtain a localized cooling with liquid nitrogen in the bearings, where the most critical temperatures are reached. Helix pitch and channel diameter had to be the best trade-off among liquid nitrogen flow capability, nitrogen inlet and outlet channels position, thermocouple hole position, mechanical stability of the insert and actual production possibility via additive manufacturing process. To this aim, as preliminary phase of the work, several insert designs have been investigated. The final design was provided with a toroidal channel and eight radial nitrogen outlets in the profile exit zone.



a) b) c) d)

Figure 1. a-c) SLM Insert: from designs to manufacturing;
d) temperatures in extrusion with nitrogen cooling.

This allowed to obtain an inert gas covered zone where the profile flowing from the die reaches the highest temperature, thus avoiding profile oxidation. Finally, two AM inserts in H13 steel have been manufactured with SLM technology with different cooling channels diameters, 1.5 and 3 mm.

In addition to the experimental SLM manufacturing of the inserts, numerical investigation of extrusion with and without nitrogen liquid cooling have been performed [2-3]. An Eulerian approach to the extrusion problem (already deformed billet) and 1D cooling channel modeling were used. An extrusion speed of 5 mm/s was set in the FE model with a 200 mm long billet pre-heated at 480 °C. The ram, the container and the die initial temperatures were fixed equal to 480 °C, 400 °C and 490 °C respectively. As results, a peak extrusion load of 2.15 MN was obtained, fully in line with the typical values of an extrusion process, with an exit profile temperature of 550 °C. Without cooling, values in the insert were very close to those reached in the aluminium part. The numerical analysis of the cooled die was carried out with a liquid nitrogen flow rate of 1 l/min. The cooling efficiency in terms of heat removal was investigated by monitoring the temperature map and the extrusion load and by comparing the achieve results with the uncooled condition. The peak exit profile temperature dropped of a 7% with respect to the uncooled condition, thus limiting the risk of defects caused by excessive process temperatures, in addition without a significant increase in the extrusion load. Near the bearings, good results were achieved with a 26% decrease of insert temperatures.

In conclusion, the manufacturing of an extrusion dies by means of additive manufacturing technologies has been proved to allow the integration of conformal cooling channels. The benefits of cooling by liquid nitrogen have been further observed with an innovative developed numerical model, thus offering a powerful tool to optimize the process efficiency.

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