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Incremental forming with Local Induction Heating on Materials with Magnetic and non-Magnetic Properties

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Abstract

Incremental sheet forming (ISF) is an agile process for small batch and rapid prototype production. Its hot variant has been developed because forming at elevated temperature increases the formability of materials and improves the accuracy of the worked parts reducing spring-back effects. Several hot ISF variants have been proposed reaching local or global heating. Here, a local heating solution has been presented by means of an induction system. This is done by a medium-high frequency generator and a heating head, continuously water cooled. The heating head, placed under the sheet and linked axially to the punch movement, warms the material locally generating eddy current in it. A laser pointer, focused on the sheet and following the punch movement, drives the generator in maintaining the desired temperature during the incremental forming phase. The first experimental trials were planned with the aim to investigate the process feasibility for forming magnetic (carbon steels) and non magnetic (titanium alloys) characterized by different forming and mechanical properties. Steel was chosen because it is a magnetic material and offers a natural resistance to the rapid change of the magnetic fields producing additional heat by hysteresis. For this reason, steel is a suitable material for the proposed heating solution. Furthermore, the effectiveness of the proposed heating system was tested on a titanium alloy, i.e. Ti6Al4V, selected because being not nonmagnetic is more difficult to heat by induction. In conclusion, first results were presented showing the applicability of the designed solution as an ISF variant. This solution can be used for improving the formability of materials hard to work at room temperature.

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Keywords: Hot SPIF; Induction Heating; Magnetic Materials; Steels; Ti6Al4V

1. Introduction

Incremental Sheet Forming (ISF) is a mature technology: introduced in 1970 [1], it had its scientific dissemination

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only after thirty years and its real exploitation more recently [2]. Several works, in fact, have been produced to highlight the applicability of the considered process in all its variants and end uses.

Automotive field is probably the first scenario that has been investigated: in 2000, Honda Motor Co., Ltd. and Amino Corp. began to utilize jointly dieless forming as possible production method for automotive replacement panels [3]. In 2001, ISF was proposed also for rapid prototyping of headlight [4]. More recently, Toyota Motor Corporation and Amino Corporation have worked together on a project to provide panels for low volume niche vehicles. The purpose has been not to form panels from raw material but to use incremental forming on existing stamped panels to add features or style for special edition vehicle. Toyota Motor Corporation has jelled it as their applied technology and they have developed outer panels in their house for specialty cars [5].

Bioengineering is another important field where ISF has been applied fruitfully: the single batch and the time reduction for a fast operation justify the introduction of ISF for producing prostheses of skull [6-7] and/or denture plates [8]. In the same field but with a secondary application, ISF has been also implemented for manufacturing customer oriented medical-support for patient rehabilitation [9].

Lastly, a recent work, inspired on the innovative concept of Industry 4.0, has proven how ISF could be implemented as a manufacturing service. Besides the integration possibilities, an adaptive control algorithm has been proposed to decrease the number of trial sheet-forming [10].

After about half century some assumptions have been established definitively: the ISF could represent a valid alternative only if single piece (low productivity) and customised shape have to be produced. Actually, it is not direct competitors of deep drawing technology since both the processes are pursued for different goals. However, ISF suitability increases in general if hard to work materials has to be manufactured. The proposed paper is focalised on the last aspect and on the introduction of an innovative technological solution for hot variant of ISF.

In 2016, Xu et al. proposed an interesting study based on the classification of the alternative technologies introduced by the researchers to perform hot-ISF [11]. They classified all the heating systems introduced by the scientific community for performing hot-ISF in: Convection, Conduction, Radiation, Friction and Electric.

The convection variant takes advantage from heat convection by using hot air blowers on the working plate [12]. The addition of heater bands, mounted on the external surface of the fixture, allowed heating the whole sheet during the forming process by conduction effects [13]. Radiation heating requires a laser light which follows the punch trajectory heating the sheet locally [14-15]. Frictional forces between the rotating tool and the static sheet are used to heat the material indirectly [16-17]. Finally, an electric current supplied by a DC power source is used to heat the sheet metal locally [18-19].

Each heating system is characterized by its own strengths and weaknesses: convection and conduction start by the hypothesis to heat the whole sheet. On the contrary, the other methods appear more suitable since they are inspired on the idea of localized heating. In fact, the material is heated just before forming to avoid keeping the entire sheet at working temperature. Moreover, these variants are characterized by a secondary positive effect due to the reduced process time required for heating. Naturally, among the local heating systems, the radiation one allows for a well-controlled heating zone and temperature, but it requires higher initial cost for the laser source. In fact, the complex and expensive equipment is a considerable process drawback which must be highlighted considering that ISF has been promoted as a low cost process. On the opposite side, the friction system does not require additional equipment but the temperature can be controlled hardly being the indirect result of process conditions. The temperature range, in fact, depends on component geometry and process variables. Lastly, the electric system represents the best compromise between process efficiency and cheapness, even if the energy control is always complicated.

Summing up, the necessity to form hard to work materials justifies the intensive literature available on the topic of Hot-ISF. However, the research is still open since each solution already proposed is characterised by pros and cons. According to that, in the present work, an innovative local heating system has been presented in alternative to the previous ones. It is based on the induction method and it can be applied for working various alloys. The equipment design is proposed in this study and the process feasibility has been investigated experimentally.

2. Designed Equipment

A new experimental equipment suitable for carrying out incremental forming (IF) at elevated temperatures was designed and assembled. For this purpose, a heating source based on an induction system was devised providing a local material heating. The idea is to heat up the sheet just during its forming such as the laser source does for the