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Analysis of electrical energy demands in Friction Stir Welding of aluminum alloys

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Abstract

Manufacturing processes, as used for discrete part manufacturing, are responsible for a substantial part of the environmental impact of products. Despite that, most of metalworking processes are still poorly documented in terms of environmental footprint. To be more specific, the scientific research has well covered conventional machining processes, concerning the other processes there is a lack of knowledge in terms of environmental load characterization instead. The present paper aims to contribute to fill this knowledge gap and an energetic analysis of Friction Stir welding (FSW) is presented. Following the CO2PE! methodological approach, power studies and a preliminary time study have been performed in order to comply with the In-Depth approach. The influence of the most relevant process parameters is analyzed regarding the required FSW energy. Finally, a few potential improvement strategies to reduce FSW energy consumption are reported.

Keywords: Friction Stir Welding; Aluminum alloys; Sustainable manufacturing; Energy efficiency

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1. Introduction

Industry sector plays a relevant role and accounts for almost 40% of the total emissions. Specifically, in the industrial sector CO2 emissions are caused both by direct and indirect emissions. The latter are due to the use of electricity and currently represent 18% of the total amount [1]. Moreover, manufacturing is responsible for about 35% of global electricity use, over 20% of CO_2 emissions as well as over a quarter of primary resource extraction [2].

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Looking specifically at metal shaping processes, the sub-sectors Fabricated Metals and Machinery (according to NAICS classification [3]) together account for 4% of the total annual energy consumed by the manufacturing sector in the U.S over the 2010 [4]. Nevertheless, the way to have a complete knowledge about the environmental impact of manufacturing processes is still long. Actually, several processes, particularly non-conventional production processes, are still poorly documented in terms of environmental footprint. In this respect, the CO2PE!-Initiative [5] was launched, this initiative has the objective to coordinate international efforts aiming to document and analyze the overall environmental impact for a wide range of available and emerging manufacturing processes and to provide guidelines to improve these. A methodology for systematic analysis and improvement of manufacturing unit process life cycle inventory (UPLCI) is provided by Kellens et al. [6]. Over the last few years two review papers have been published in the domain of discrete part manufacturing [7, 8]; both of the papers presented the state of the art of sustainable manufacturing processes under different perspectives. Form these papers it is possible to realize that researchers have mainly paid attention to machining processes. Actually, studies addressed at analyzing and modeling the energy efficiency of turning, milling and grinding are already available. All the others discrete metal working processes have been only partially analyzed or even totally neglected.

As far as sheet metal working processes are concerned a few studies have been published though. Some paper focused on forming processes; Cooper et al. [9] presented and environmental analysis of aluminum sheet stamping processes, Santos et al. [10] proposed a comprehensive analysis on the energy efficiency of bending processes while Kellens et al. [11] analyzed the improvements in electrical energy demand by optimizing the press brake architecture. A comprehensive electrical energy demand analysis of Single Point Incremental Forming (SPIF) has been developed by Ingarao et al. [12]. As regards separating processes, some energy and resource efficiency analysis on laser cutting [7, 13] and on punching [14] have been already developed.

In the last decades, researchers have developed new joining technologies to radically settle all the issues linked to the melting-based welding techniques. The solid-state bonding technology allow to obtain sound weld without reaching the melting temperature of the base material. Solid bonding phenomenon occurs in metal materials when a plastic flow is subjected to high pressure and temperature. The third variable that affects the process is the period of time the cited condition are kept. In particular, Friction Stir Welding is a solid-state welding process developed and patented in 1991 by The Welding institute (TWI) of Cambridge. This technology allows the joining of sheet metals thanks to a complex plastic flow of material caused by the action of a properly designed rotary tool that is plunged nearby the edges of the sheets and moved along the welding line. During the process, no filler is used and temperature results to be under the melting point of the base material so that all the issues linked to the melting and solidification of the material are avoided. Different phases can be identified during the process: at the beginning, the tool is plunged at constant velocity in the metal until the bottom of the pin is a few tenths of millimetre far from the bottom of the sheets. The initial inverse extrusion caused by the pin plunging is arrested by the shoulder that consequently generates heat by friction. The material softening caused by the heat flux enable an effective stirring action exerted by both the shoulder and the pin. When the material is heated up enough, the tool is moved along the joining line forming the weld. The process parameters commonly varied during experimental campaigns are the tool rotation and feed rate, which directly affect the heat generation and stirring action, as well as the tool geometry. Joints produced with different combinations of the cited parameters can hence be analysed in order to find out the best configuration.

As a solid-state welding process, it is accepted that the heat input in to the joint is less than the one needed for melting based welding of the same materials. However, to the authors knowledge, only a very limited number of studies can be found in literature focused on the quantitative evaluation of the electrical energy demand of the process. In particular, Shrivastava et al. [15] published the results of a research focused on the development of an analytical model able to predict the energy consumption in FSW of two different aluminium alloys, i.e. AA6061-T6 and AA7075-T6. The obtained results highlighted that power can be estimated based on specific FSW energy, weld area and feed rate. In a second paper by the same authors [16], a comparison is made between energy consumption on FSW and GMAW for variable thickness AA6061-T6 alloy sheets. It was found that FSW consumes 42% less energy as compared to GMAW and utilizes approximately 10% less material for the design criteria of similar maximum tensile force, with a resulting reduction of greenhouse gas emission of 31%. For both the studied the machine used for FSW experiments was a CNC milling machine, which significantly differs in terms of architecture from a dedicated FSW machine, for which force controlled welds can be made through a proper oleodynamic controlled system. Working cycle time study as well as a power study have been performed.