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Cost modelling and sensitivity analysis of wire and arc additive manufacturing

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Abstract

With the proliferation and diversification of metal additive manufacturing (AM) processes in recent years, effective decision tools for process selection are of increasing importance. This paper presents a novel time activity based cost model for Wire-Arc Additive Manufacturing (WAAM), an emergent metal AM technology. The full process chain is modelled and a tool-path based deposition cost employed. The results show that WAAM has significant potential as a cost-effective manufacturing approach compared to other AM and conventional CNC machining methods. Sensitivity analysis identifies indirect costs as a key cost driver generally, with parts per build plate, and shielding cost having significance for smaller and larger parts respectively.

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Keywords: Wire and Arc Additive Manufacturing; Cost Modelling; WAAM; Additive Manufacturing

1. Introduction

Additive Manufacturing (AM) has become the subject of a substantial amount of research due to promising industrial potential, with AM products and services set for sales of $26 billion worldwide by 2021[1]. The concept of creating metal products additively has seen an increased uptake in recent years. AM provides opportunities for

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reduced weight and cost savings and has been especially prevalent in the aerospace industry where there have been instances of conventional manufacturing processes being replaced by metal AM processes. Processing limitations have led to the diversification of metal additive manufacturing techniques especially within the categories of Powder Bed Fusion (PBF), Binder Jetting and Direct Energy Deposition (DED) [2], each with their distinct benefits. Understanding the performance of metal AM processes in terms of cost effectiveness is essential for effective deployment and further uptake of AM. Cost effectiveness is especially important as a measure because industrial standards of quality control are rarely achieved in metal AM. The combination of knowledge of process capability and effective cost modelling can provide a valuable insight into the potential cost escalation or "real cost" of a particular AM process.

Wire and Arc Additive Manufacturing (WAAM), is a DED approach that is seeing considerable interest due to its ability to create large metal products faster than powder-based alternatives, with deposition rates up to 4 kg/hr [3]. The process uses an electrical arc as a heat-source to melt feedstock metal wire, which is deposited onto a base plate [4]. The WAAM process comprises successive cycles of melting, depositing and cooling to result in a near-net shape deposit. Cold-work through rolling may be subsequently employed to improve microstructural properties and relieve residual stresses induced by thermal cycles incurred through the deposition process [5][6]. WAAM with an integrated roller consists of an arc torch is shown in Figure 1 [5]. To achieve end-product status, heat treatment for residual stress relief and/or to develop mechanical properties and finish machining is required [8]. Compared to powder based AM methods, WAAM offers several distinct benefits. In certain materials, directed deposition and cheaper wire feedstock mean that cost be reduced significantly compared to PBF. Further, processing issues such as powder agglomeration, recycling are overcome. Concerns with development of full density and microstructure of non-heat treatable materials in PBF and Binder Jetting may be overcome by the inter-pass rolling which is easily implemented in WAAM. To supplement these benefits, effective cost modelling of the WAAM process is required. This paper introduces a method of generating a detailed Activity Based Cost model for WAAM. A literature review of the current cost models developed in metal additive manufacturing is provided in section 2. The method adopted for cost model development is explained in section 3. The results of cost model and sensitivity analysis are presented in section 4. The outcomes and advantages and disadvantages of this method are discussed in section 5, with final conclusions in section 6.

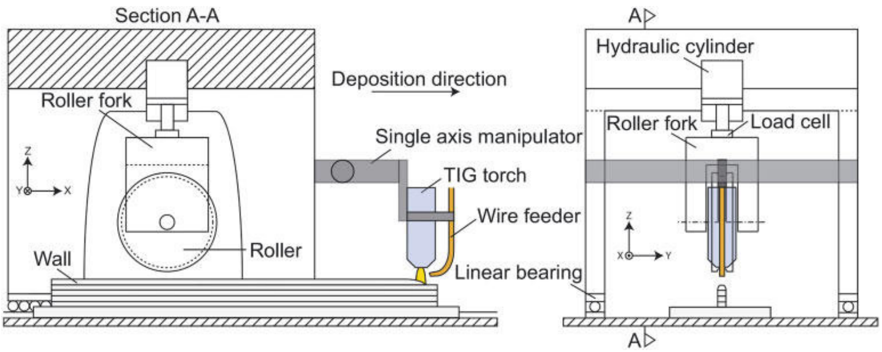

Figure 1 Schematic of Wire and Arc Additive Manufacturing with integrated rolling [5]

2. Literature review of cost modelling in wire and arc additive manufacture

Cost is usually the key point for decision making and cost modelling followed by a break-even analysis is a key method for determining manufacturing process selection. As AM technology has matured it has become possible to compare cost effectiveness with the results achieved by traditional technology. A consequence of process maturation, is that processing uncertainty is reduced allowing increasing accurate cost models to be developed. Cost models used for traditional production methodologies focus on material and labor costs, while modern automated manufacturing processes need cost models able to consider the high impact of investments and overheads Ruffo *et*