Remanufacturing H13 Steel Moulds and Dies Using Laser Metal Deposition

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Abstract. The exploitation of Additive Manufacturing (AM) in the repair and remanufacture of industrial components, such as moulds and dies, has become an emerging research area due to the expected reduction of replacement cost and the promise of better mechanical and wear resistance properties – moreover, the use of remanufacturing standards ensures a greater than or equal to warranty part quality. Further studies plan to utilize Laser Metal Deposition (LMD) to remanufacture artificially worn H13 Steel samples, allowing benchmarking studies to be conducted in order to compare the mechanical and wear resistance performance of LMD against current welding repair technologies. The specimens will be subjected to an accelerated pressure and elevated temperatures schedule, simulating the loading cycles during the use of the die sets. The effects on the resulting part properties of different process parameters setup, including the type and characteristics of the deposited powder will be studied.

Keywords. Additive Manufacturing, Laser Metal Deposition, Forging, Screw Press, Forging Die, Remanufacturing

1. Introduction

With the view to ever increase operational and manufacturing efficiency to meet carbon emission targets [1, 2], [3] and remain financially sustainable - industries, such as the UK Forging Industry, have begun to strongly consider remanufacturing as a promising method of extending die life [4]. This paper focusses on forging dies due to their widespread use in various industries, especially for High Value Manufacturing (HVM) applications in the aerospace and automotive sectors. Furthermore, the high replacement costs and long lead times for new dies are driving factors in the research [5].

The paper reviews currents methods of die repair and proposes a new model of remanufacturing that seeks to improve efficiency and introduce early stage problem identification. Due to the high costs involved in undertaking experimentation using metal AM, LMD has been identified as preferred candidate as a product of a literature review [5].

The following methods have been highlighted as being suitable for the remanufacture of a forging die;

1. **Flood Welding** – Flood welding firstly requires the removal of the crack via ‘scarfing’ (a form of material removal thought to inhibit crack propagation

using a specialist welding tool) [2]. The repair area is then sealed to prevent overflow using welded metal panels to enclose an area. Following this step the die is then flooded with liquid metal and allowed to cool, ready for machining. Flood welding has also been reported to extend die life by up to 50% [2], [6].

2. **Laser Metal Deposition** - The Laser Metal Deposition (LMD) process involves a laser beam used to form a melt pool on a metallic substrate, into which powder is fed. The powder melts to form a deposit that is fusion bonded to the substrate. Both the laser and nozzle from which the powder is delivered are manipulated using a CNC robot or gantry system - further explained in section 3 [7].
3. **Electron Beam Additive Manufacturing** - Electron Beam Additive Manufacturing (EBAM) works by depositing metal (via wire feedstock), layer by layer in a vacuum environment, until the part reaches near-net shape and is ready for finish machining [8].
4. **Wire+Arc Additive Manufacturing** – Controlled by CNC, Wire+Arc Additive Manufacturing (WAAM) delivers a solid metal wire feed stock into the path of either Tungsten inert Gas (TiG) or plasma transferred arcs to create semi-complex, 3D geometries. It can achieve a buy to fly ratio of typically 1.5 [9], [10].

This paper will focus on the feasibility of LMD as a viable Remanufacturing method.

2. Removal of Cracking & Wear from Die Sets

The two main failure methods identified in forging dies sets are ***cracking*** and ***wear***, typically occurring as a product of severe thermal stress and high compressive forces in tight radii/geometries. Cracking can result in catastrophic failure of the die and wear in unsatisfactory component quality [6].

2.1. Crack Removal

A site visit was conducted at a die repair company in England, where HVM forging and OEM companies throughout the UK send their worn or damaged die sets for repair. At present, one of their repair methods is flood welding, as previously described in section 1 and further displayed below in **Figures 1a – 1d**.

Figure 1a. **Figure 1b**. **Figure 1c.** [11] **Figure 1d.** [11]

1a Crack Identification, **1b** Scarfed Die, **1c** Flood Welded Die & **1d** Die after Machining. ***NB: These are all different dies***

As with all technologies there are limitations in their application. Literature reviewed has presented a possible limiting issue – the formation of a, potentially, brittle carbide interface layer, located between substrate and deposited material. [12], [13]. Further, undesired high internal stresses could be generated due to non-uniform shrinking and undesired phase changes as a product of fast cooling rates especially for high carbon steels [14].

3. Laser Metal Deposition

Following a literature review process Laser Metal Deposition was selected for further analysis due to the achievable micro-structural properties - which are similar to that of die quality H13 Steel. A site visit was conducted at a LMD company in England, UK where a bespoke system has been constructed and operates commercially.

Further to the brief description in section 1, the below diagram (**Figure 2**) illustrates in greater detail how the LMD process works.

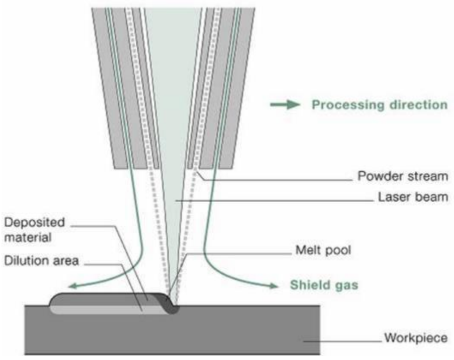

Figure 2. LMD Diagram [7]

Case studies have confirmed both a financial and environmental benefit of using LMD as a means of remanufacturing a stamping tool [5].

Nonetheless, AM processes and Remanufacturing should not be viewed as panaceas - flood welding and newly machined dies still play a vital role in the supply chain.

3.1. Remanufacturing using LMD vs. Machine from Solid

To assess the relative economics of remanufacturing and Machine from Solid (MFS) it should be assumed that the product (die set) has been damaged or worn to an extent where it is no longer fit for purpose. Thus, the requirement is simply to attain a product that is fully functional, with performance (and warranty) levels equivalent to, or greater than the previous product in order to resume production. Both remanufacturing and MFS satisfy this requirement [15].

However, we are presented with three cases where product End of Life (EoL) will occur in this context;

1. EoL through failure or *unanticipated* wear
2. EoL through calculated wear
3. EoL through design obsolescence

The view could be taken that in the cases of 1 & 3 that remanufacturing would offer the quickest route back to production – however, case 2 would allow for the preemptive ordering, manufacture and delivery of a new die set, enabling continuous production [5]. As such, for the purposes of this paper, the following assumption has been made - EoL has occurred unexpectedly and the factory operators are attempting to restart production in the quickest and most economical method.

3.2. Defining Remanufacturing

Presently there is still ambiguity surrounding the definition of remanufacturing, the British Standards Institute (BSI) defines remanufacturing as a process to:

> *"return a used product to at least its original performance with a warranty that is equivalent or better than that of the newly manufactured product"* [16].

This clearly defines the *main objective* of any remanufacturing operation – that is to ***"return a product to at least its original performance"***. Therefore, this dictates that the performance characteristics of a remanufactured product should be, as a minimum, ***satisfactory*** or equal to that of a new MFS product.

3.3. Proposed Remanufacturing Method for Near Surface Cracking using LMD

At present dies are only checked visually for damage, therefore the extent, or indeed the presence of internal cracking and or defects is unknown [2]. If a die has deep/extensive internal cracking then the view may be taken not to undertake remanufacturing as this may no longer be a financially viable option. Furthermore, extensive operations may no longer yield a mechanically sound die set. The *whole-life Cost* (C_{wl}), with respect to remanufacturing, can be calculated using the following equation [16]:

$$C_{wl} = \frac{C_{oem} + nC_{rmf} + C_{eol}}{1 + \mathrm{n}}$$

Where;

C_{oem} is the cost of the original manufacture
C_{rmf} is the cost of Remanufacture
C_{eol} is the end-of-life cost
n is the number times the product is Remanufactured

Thus, due to the high costs involved and the potential lost revenues incurred in an unnecessary remanufacturing operation, a methodology that could identify, from an early stage, which process is most suitable would seek to lessen the financial risk. Therefore, a new process methodology for the remanufacture of die sets using LMD is proposed below in **Figure 3** [15].

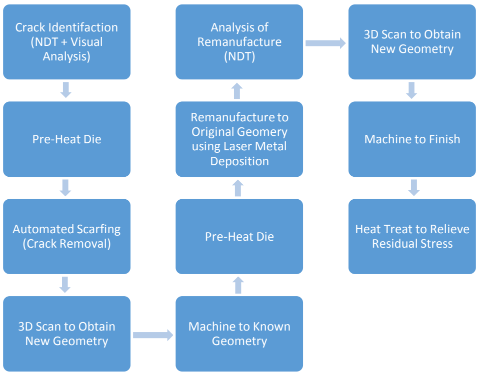

Figure 3. Proposed Remanufacturing Method for Near Surface Cracking using LMD

Following crack identification an automated scarfing process is undertaken, informed by data received from NDT. 3D scanning will then obtain a new geometry for the purposes of accurate and efficient machining. After machining, material powder is deposited in the cavity using LMD. Additional NDT analysis of the deposited material and substrate will assess the bond competency and build success. The component is then 3D scanned and blend machined to finish. During this process it is imperative to pre-heat and heat treat to relieve residual stresses and maintain mechanical properties [2].

4. Conclusion & Future Work

The variety of issues and limitations identified surrounding the effective use of LMD as a means of remanufacturing forging dies requires diligent consideration. The literature review and site visits have raised an array of interesting research questions which will be scrutinized in our future work.

A series of experiments have been designed to address the aforementioned research challenges. They will use a LMD to fill H13 Steel cavities with a metal alloy, thus simulating aspects of Figure 3 [16]. These will then be analyzed to gain the microstructural properties prior to and following mechanical and non-destructive testing, with the view to measure any critical change and or cracking.

Further research should be undertaken to identify if the thermal cyclic stresses, similar to that experienced in forging cycles, will lead to internal cracking of the interface layer due to the brittle nature of carbides.

Additionally, alloys with non-carbide-forming elements should be studied for their suitability for their use in LMD and ability to form comparable mechanical properties to H13 Steel. The team are working with a LMD powder material developer to assess the suitability of a developmental alloy that seeks to prevent the formation of carbides. This will be undertaken by the aforementioned experimental method.

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References

[1] European-Commission, "Commission staff working paper accompanying the proposal for a directive of the European Parliament and of the Council on waste electrical and electronic equipment (WEEE) (recast) - Impact Assessment {COM(2008) 810 final} {SEC(2008) 2934}," Environment, Ed., ed. http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52008SC2933#: EU, 2008.

[2] Die Life Ltd. (2016, 25/11/16). *Die Life Brochure*. Available: http://www.dielife.com/downloads/brochure.pdf

[3] UK Government, "2010 To 2015 Government Policy: Climate Change International Action," D. o. E. C. Change, Ed., ed. www.gov.uk: UK Government, 2015.

[4] A. Chapman, C. Barlett, I. McGill, D. Parker, and B. Walsh, "Remanufacturing in the UK: a Snapshot of the UK Remanufacturing Industry," *Full Report. Centre for Remanufacturing and Reuse,* 2009.

[5] W. Morrow, H. Qi, I. Kim, J. Mazumder, and S. Skerlos, "Environmental aspects of laser-based and conventional tool and die manufacturing," *Journal of Cleaner Production,* vol. 15, pp. 932-943, 2007.

[6] D. Hammock. (2007, 09/04/2016). *Welded Repairs Extend Forging Die Life*. Available: http://www.forgemag.com/articles/83738-welded-repairs-extend-forging-die-life?

[7] Laser Additive Solutions. (2015, 22/01/16). *Laser Metal Deposition Diagram* Available: http://www.laseradditivesolutions.co.uk/

[8] Sciaky Inc. (2016, 06/02/2016). *Make Metal Parts Faster & Cheaper Than Ever with Electron Beam Additive Manufacturing (EBAM™) Systems or Services*. Available: http://www.sciaky.com/additive-manufacturing/electron-beam-additive-manufacturing-technology

[9] A. D. Addison, Jialuo Martina, Filomeno Lockett, Helen Williams, Stewart "Manufacture of Complex Parts using Wire+Arc Additive Manufacture," presented at the Titanium Europe 2015, Birmingham, UK, 2015.

[10] A. Addison, "Large Scale Additive Manufacture for Space Applications," Cranfield University, www.innovateuk.gov.uk, Powerpoint Presentation2015.

[11] D. Lee. (2015, 06/08/20116). *Making "Cents" Out of Welding Die Blocks*. Available: http://www.forgemag.com/articles/84387-making-cents-out-of-welding-die-blocks

[12] A. S. C. D'Oliveira, P. S. C. da Silva, and R. M. Vilar, "Microstructural features of consecutive layers of Stellite 6 deposited by laser cladding," *Surface and Coatings Technology,* vol. 153, pp. 203-209, 2002.

[13] M. SImonelli, "Microstructure evolution and mechanical properties of selective layer melted Ti-6Al-4V," Doctor of Philopshy, Department of Materials, University of Loughborough, 2014.

[14] D. Junker, O. Hentschel, M. Schmidt, and M. Merklein, "Tailor-Made Forging Tools by Laser Metal Deposition," *Key Engineering Materials,* 2015.

[15] J. Allen, "An investigation into the comparative costs of additive manufacture vs. machine from solid for aero engine parts," DTIC Document2006.

[16] British Standards Institute, "Design for Manufacture, Assembly, Disassembly and End-of-Life Processing (MADE) Part 2: Terms and definitions," British Standards Institution http://www.bsigroup.com/ BS 8887‑2, 2009.