MARADÓ FESZÜLTSÉGEK ADDITÍV GYÁRTÁS SORÁN

RESIDUAL STRESSES IN ADDITIVE MANUFACTURING

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ABSTRACT Residual stress is the stress that stays in a static body that is in balance with its circumstances. It can have a significant impact on the efficiency of a material or the component life. Beneficial residual stresses might also be introduced on purpose. Residual stresses are still more difficult to forecast than the stresses that they overlay in service. This paper illustrates the effect of residual stress in the industry and how to measure it. Then, shows the residual stress in both metal and polymer Additive Manufacturing with some research findings.

1. INTRODUCTION

It is typically possible to determine the stresses to which an element is subjected in service using modern mathematical and computational approaches. This is insufficient for making a precise prediction about component efficacy. In fact, in so many situations where unexpected failure has happened, it has been associated with the appearance of residual stresses, which have combined with service stresses to significantly reduce part lifetime. Compressive stresses, on the other side, are occasionally intentionally created, like in shot peening, which can be used to enhance fatigue resistance. Additive Manufacturing (AM) technologies can be seen as a cornerstone of the next industrial revolution [1]. At various levels, AM technologies have a significant impact on society [2]. However, a basic understanding of the relationships between materials and techniques is critical for improving product quality and hastening the adoption of AM in modern manufacturing systems. The proper knowledge of residual stress is one of the challenges of AM. Materials are deformed nonuniformly throughout material manufacturing processes due to external effects such as changes in temperature, unequal mechanical deformation, or phase change, producing residual stress that stays in the component after the thermo-mechanical processing. They have a direct impact on the effectiveness of a manufactured part (corrosion resistance, distortions, fatigue life, dimensional accuracy, crack propagation, etc.). More than 50% of the mechanical failure is due to corrosion and fatigue [3]. Residual stresses are present in all manufacturing processes; but, with appropriate handling, they can potentially be useful, such as creating compressive stresses in the surface and sub-surface layers of parts can improve fatigue resistance and Stress Corrosion Cracking (SCC) prevention, while tensile residual stress has the reverse effect [4].

Residual stresses lead to negative consequences in additive-produced components such as thermal cracks, distortions, and tensile stresses in the outer surface. These flaws wreak havoc on the industry's ability to produce high-quality components.

2. FAILURE BY RESIDUAL STRESS

A failure's impact may be measured in two ways: in terms of the risk to human life and terms of the financial cost of the failure. Many case histories, such as the collapse of a high-strength steel frame in a US army jet fighter, would be deemed high impact in both aspects [5]. A bridge disaster is described in another case study. These instances clearly show that even seemingly minor residual stress can result in catastrophic breakdowns[6]. Fairfax E.J., Steinzig M. [7] used ASM Failure Analysis Database™ to analyze 147 case histories of failure analysis and the results were illustrated in figure 1.

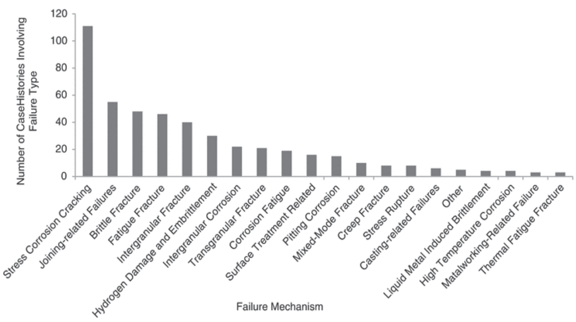

Figure 1 Number of cases describing the residual stress-related mechanical failure [7].

SCC was responsible for 111 of the failures, then joining-related failures, brittle fractures, fatigue fractures, and intergranular fractures with 55, 48, 46, 40 respectively. Because SCC occurs in more than double as many case histories as the next most prevalent failure mode, a closer examination of SCC failures is needed. Figure 2 shows that residual stress is one of the factors that cause SCC [8]. If the degree of residual stress is large enough just to produce dislocation movement (strain or yielding) at localized areas, residual stresses in the material are sufficient to produce SCC.

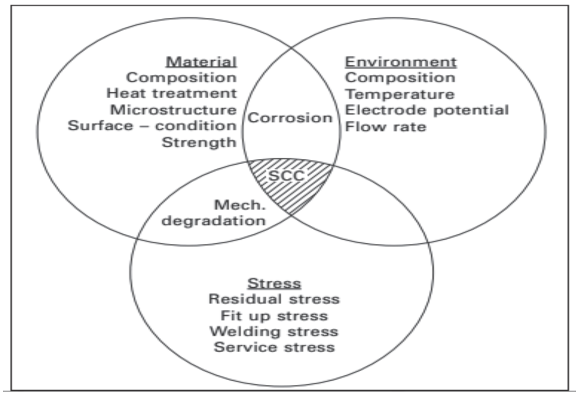

Figure 2 Factors affecting SCC [8].

3. MEASURING THE RESIDUAL STRESS

The size and angle of residual stresses are reversed by output strains or corresponding displacements, which belong to the area of inverse dilemmas research. According to the test concept, measuring techniques are currently classified into two groups [9]. Destructive testing procedures, such as chemical and mechanical methods. The principle of the destructive method entails removing and measuring the stress in the material in a certain way. The residual stress can be determined using the elastic mechanics concept by evaluating the strain or displacement of the area. Destructive testing procedures are relatively straightforward to carry out, and test accuracy is usually pretty good, although surface damage is sometimes unacceptable. Nondestructive testing procedures that evaluate the physical features of the material itself with types of equipment were quickly implemented to avoid the specimens from being damaged. These two categories can be seen in figure 2 [10].

4. RESIDUAL STRESS IN METAL ADDITIVE MANUFACTURING

The AM method includes layer-by-layer heating, melting, and solidification of an alloy using a movable source of heat like a laser or an e – beam [11], [12]. Consequently, different parts of the component are heated and cooled repeatedly [12]. Metal AM's distinct thermal cycle is defined by fast heating, cooling rates, and melt back, which involves continuous melting of the surface material layer and re-melting of previously formed layers [13], [14]. These temperature gradients lead to produce residual stress and figure 3 shows the failure of residual stress in AM [15].

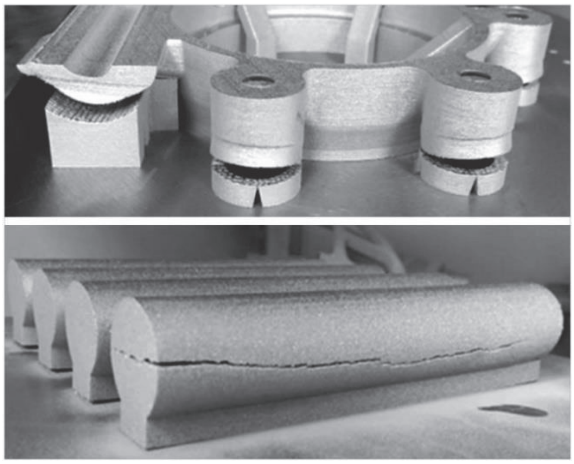

Figure 3 Residual stress effect in AM [15].

There are two main types of metal 3D printing: Direct Energy Deposition (DED) and Powder Bed Fusion (PBF). A lot of researches have been done to investigate and minimize the residual stresses in metals. The most common method of reducing residual stress is to lower the temperature difference by heating up the raw material or the substrate [16]– [20]. Mukherjee, T., W. Zhang, and Tarasankar DebRoy [21] used a three-dimensional, transient heat transfer and fluid flow model to calculate the residual stress in Inconel 718 and Ti-6Al-4V and found that by decreasing the layer thickness during AM, residual stresses can be greatly reduced. Yaghi, Anas, et al [22] used PBF to print stainless steel 316 L impeller and investigate the residual stress by the GOM approach for evaluating distortion and Electronic Speckle Pattern Interferometry (ESPI) and the Contour Method for measuring residual stresses, and then they used finite element (FE) method to compensate the distortion to print new impeller with more than 50% reduced in distortion.

5. RESIDUAL STRESS IN POLYMER ADDITIVE MANUFACTURING

51% of parts produced by AM systems in the industry are from polymer, 29.2% from polymer and metal, and 19.8% from metal [23], [24].
There are many printings technology used for polymer AM and one of the most used is Fused

Filament Fabrication (FFF) or some called it Fused Deposition Modelling (FDM) which has key features like the capacity to produce things with functionally graded characteristics (density, porosity, and mechanical properties).

Researchers have made significant efforts to detect residual stresses in additively produced components. Karalekas and Rapti, [25] studied the processing dependency of SLA solidification residual stress utilizing the hole-drilling strain-gage method of stress relaxation by using epoxy-based photopolymer. Karalekas and Aggelopoulos [26] examined the shrinking stresses in an acrylic photopolymer resin that has been SLA cured. The residual stresses in ABS components produced by FDM utilizing the fiber Bragg grating technique were investigated by Kantaros et al [27]. Casavola et al. [28] used the hole-drilling approach in and electronic speckle pattern interferometry to quantify residual stress in FDM ABS components. These studies have made it much easier to determine residual stresses in additively produced components. However, additional research into characterization methodologies, printing materials, and processing settings is still needed to reduce the negative consequences of residual stress like environmental factors, build part orientation, process parameter…etc [29].

Finally, Zhang, Wei, et al [30] investigate the residual stress by printing three different types of acrylonitrile-butadiene-styrene (ABS) using X-ray micro-computed tomography. They found that there is a positive correlation between the printing speed and the porosity and residual stress. Raster angel and layer thickness also affect the mechanical properties.

6. CONCLUSION

Residual stress is a significant factor in the industry, and it must be evaluated deeply especially in AM. This paper gave an overview of the definition of residual stress and the effect on parts by showing the measurements methods. The latest research and findings in the investigation of residual stress in metal and polymer AM were explained.

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