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Application of Additive Manufacturing in Marine Industry

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ABSTRACT: The advantage of additive manufacturing (AM) (e.g. reasonable time and expense in prototyping, and reliable product) has triggered the idea of using this method in manufacturing of marine vessels components. The current article tries to introduce basic concepts of AM method and its application in marine industry; have a glance at additive-manufactured parts microstructure; elaborate the challenges in investigation of mechanical properties of AM products; in order to makes this technology more known to domestic industry.

Keywords: *Additive Manufacturing; Metal 3D Printing; Marine Applications*

INTRODUCTION

Additive manufacturing (AM) (i.e. also known as 3D printing) is considered as the next industrial revolution in manufacturing of intricate components while benefited from high precision with less time and expense in production in respect to traditional methods, (Lloyd's, 2016). Due to sheer versatility and advantages, its application has been extended from dentistry to aerospace engineering. Since 3D printing is a convenient way of prototyping, ship industry has shed light on this technology specially in innovation centers. 3D printing is a convenient way of manufacturing and prototyping marine vessel components (e.g. rudder and proproller), as Hyundai Heavy Industry (HHI), as the largest ship building company in world, showed prodigious desire over employing this method. HHI announced that by localizing this technology, South Korea can benefit 1.8 billion dollars annually (Ship-Technology, 2016).

Marine industry in Iran has substantial protentional to develop in various sectors (e.g. renewable energy devices, AUV and ROV, large vessels and high speed crafts), because of unique features of Persian Gulf and Caspian Sea. Recently, the importance of research-based projects for progress in this scope (i.e. marine industry) is well-understood, and demand for innovative methods has been growing; therefore, this paper tries to introduces some fundamental concepts in AM and solid mechanics in order to convey a perspective over the utilizing this technology for producing marine components.

MATERIALS AND METHODS

Additive manufacturing is a new term in production of mechanical parts in which a mechanical part is designed by a CAD system and through a reverse engineering, the process of building a part layer-by-layer is digitized as a input code, (SIMULIA, 2016). Laser Beam Manufacturing (LBM) of metals is one of the most widespread method in metal 3D printing in which fine powder of pure metals such as steel, titanium, and aluminum, or their alloys (e.g. Ti-6Al-4V) are used as feedstock; spread in thickness of 20 µm -100 µm across work area which dimensions can vary from50 mm * 50 mm to 800 mm * 400 mm, (Herzog *et al.*, 2016).

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Any layer of the object is built once a laser beam, whose speed can be up to 15 m/s, and power depending on the application ranges from 20 W to 1 kW, (Solutions), is projected on the deposited powder; gets the powder molten into the shape of desired layer, Fig. 1. Needless to say, the heat of molten material influences the temperature of certain radius of its vicinity, causing a small but not negligible inaccuracy (roughness) for the layer. After laser withdrawal, the melt pool and the already built section of the object is fused; holding for following layer to be manufactured. The whole process is implemented in a sealed chamber, filled with an inert gas (e.g. N_2 or Ar), for the entire process to prevent unwanted chemical reactions (e.g. oxidation). Electron Beam Manufacturing (EBM) and Laser Metal Manufacturing are the two other common methods in metal 3D printing, (Herzog *et al.*, 2016; Van der Schueren and Kruth, 1995).

Feedstock

The most common material in producing feedstock are, steel, Ti and its alloy, Al alloy and Ni-based super-alloy. The way the feedstock is processed (atomization), is a decisive factor in the quality of final product. Generally, there are two methods in producing feedstock, which are atomizing a metal by water, or gas. Water is considered as a reasonably economical method while suffering some drawbacks as; producing grains with non-uniform sizes and asymmetric shapes (i.e. due to high cooling rate) (Dawes, Bowerman, and Trepleton, 2015), effecting the density of powder-bed and consequently final mechanical part (German, 1997); including oxygen in particles which is supposed to influence the melt pool exacerbating material composition of final product, (Pinkerton and Li, 2005). Besides, the water atomization is limited to non-reactive material (e.g. steel) and cannot be used for the metals tending to have chemical reaction (e.g. titanium), (Herzog *et al.*, 2016). The alternative method to overcome limitations and disadvantages of water atomization, is gas processing by which the cooling rate is slower and the uptake of oxygen is lowered; hence, producing spherical shaped (i.e. nearly same size of water atomization) without oxidation in layers.

The common materials used in AM are brought in Table 1, (Jerrard *et al.*, 2009; Li *et al.*, 2010; Li *et al.*, 2011; Niendorf *et al.*, 2013; Riemer *et al.*, 2014).

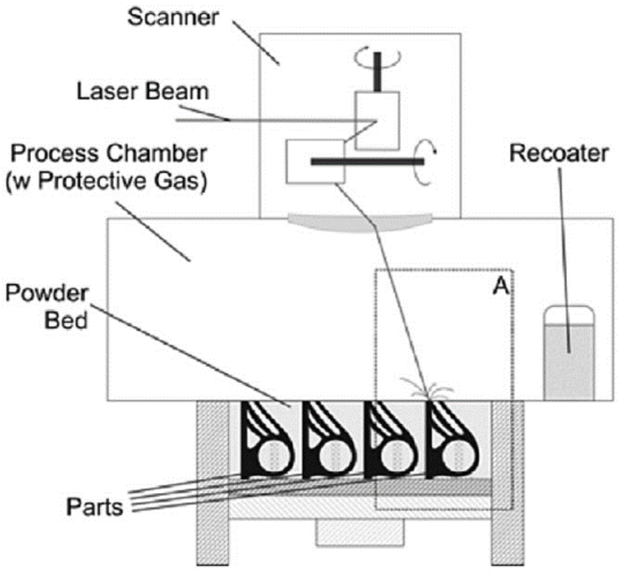

Fig. 1: Laser Beam Manufacturing set-up, (Herzog *et al.*, 2016).

Table 1: The most common material for AM

Material	Alloy
Steel	Austenitic steel alloys as: AISI 316L/EN: 1.4404/X2CrNiMo17-12-2 AISI 304L/EN: 1.4306/X2CrNi19-11 Maraging steel (18Ni-300/1.2709/X3NiCoMoTi18-9-5) precipitation hardenable stainless steels, as: (17-4 PH/EN: 1.4542/X5CrNi- CuNb16-4/AISI: 630) (15e5 PH/EN: 1.4545/X5CrNiCu15-5) martensitic cutlery grade (AISI 420/EN: 1.4034/X46Cr13)
aluminum	Hardenable alloy as: EN AW-7075 of the Al-Zn 7xxx series AlSi10 Mg (EN AC-43000)
titanium	Ti-6Al-4V Ti-24Nb-4Zr-8Sn Ti-6Al-7Nb

Effect of AM process on the mechanical properties

The properties of final AM products depend on 1) production of feedstock, and 2) fabrication process. In LBM, the powder bed is molten by high energy of laser beam; by withdrawal of laser the melt pool starts solidifying (i.e. in which the rate of solidification is faster in build direction due to higher heat conduction); and the solid section of object is exposed to repetitive re-heating and re-cooling which probably alters the final product as well, (Tan *et al.*, 2015).

One of the principal goal in manufacturing AM parts is final product having more than 99.5% density, as porosity is determinately factor for mechanical properties (e.g. static failure, crack propagation). The energy of laser plays significant role in density of material. In case the energy is not enough, the unmolten particle exists in pool, causing irregular shape porosity (i.e. sharp end), whereas the excessive energy brings about trapped oxygen in layers; hence small spherical porosity, (Thijs *et al.*, 2010).

As it is obvious, the grain size, which is itself influenced by cooling rate, changes the mechanical properties. As a common characteristic, the product of AM comes with fine small-grained microstructure, due to high cooling rate in respect to the conventionally manufactured steel, (Gong *at al.*, 2012). A small-grained texture provides high yield strength, toughness, and ductility, (Todd *et al.*, 1994); hence AM delivers competitive components to traditional methods (e.g. casting). Two parameters are influential in the grain size; the size of melt pool; and the inter-layer heat conduction (i.e. reheating and re-cooling of the following layers). If the size of the melt pool increases (e.g. thickness) the cooling process becomes slower, resulting in coarse-grained texture, (Niendorf *et al.*, 2013). As it was mentioned, the higher cooling rate in building direction leads to anisotropic properties in which the build direction possesses higher strength in respect to the two orthogonal directions. This can be a crucial point in choosing direction of AM layers.

Instability of any slender structures depends upon factors as; loading; initial imperfection. In AM parts, the anisotropy of material and porosity are influential as well as foregoing parameters. It is crucial to be investigated whether the pattern and size of porosity as an initial defect can trigger the instability. Extensive researches seem to be essential on the anisotropy of material and buckling of parts in different direction, same as the series of research which already carried out on subsea flexible pipes as a structure showing different strength in three different directions without any symmetry plane, (Cooke and Kenny, 2014; Ebrahimi *et al.*, 2015a, 2015b, 2016).

While because of anisotropy of material, the fatigue resistance of object is dependent upon direction, (Kohar *et al.*, 2016; Muhammad, 2014), the type and size of porosity is so important in fatigue life of product. In principal, porosity lower the fatigue life and a sharp porosity exacerbate the situation, *(Stephens et al.*, 2000).

The complexity of fatigue analysis becomes double for component exposed to the type of loading in which the principle stress varies in time (e.g. propeller), (Stephens *et al.*, 2000), because of the material anisotropy, (Belytschko *et al.*, 2009). Any propeller, particularly in high speed vessels, experiences force components in three different directions, Fig. 2 (i.e. trust as axial load; drag which produces tangential and radial ones), while these forces varies in time due to ship fluctuations (e.g. heave), cavitation behind propeller, vessel slamming, and two phase flow for propeller (i.e. surface piercing propeller).The scenario worsened, if the anisotropy of material is added to the complexity of fatigue analysis in foregoing complex loading.

CONCLUSION

In this overview article, the applications of AM in different scopes and importance of using this technology in global and domestic marine industrieswere emphasized; material properties in microstructure scale was discussed; and some points regarding mechanical analyses of final products were mentioned. Based on the complexity of AM applications in marine industry, extensive and coherent researches seem to be crucial to identify obscurities, however, utilizing AM in marine basins to build prototypes (e.g. renewable energy devices, high speed craft stabilizer) still can facilitate the researchand expedite progress in marine sector.

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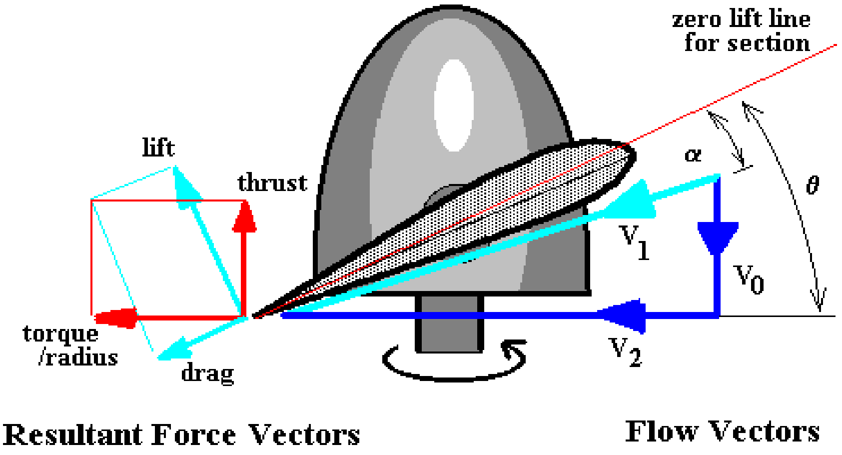

Fig. 2: Force component on a ship propeller, (Southampton).

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