Doctoral Dissertation
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Analysis of sinter-based additive manufacturing techniques for the sustainable production of objects for the fashion industry

Marta Ceroni

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Supervisors
Prof. M. Actis Grande, Supervisor
Prof. P. C. Priarone, Co-Supervisor
Prof. L. Settineri, Co-Supervisor

Doctoral Examination Committee:
Prof. Cristina Berges, Referee, Universidad de Castilla-La Mancha
Prof. Elena Colombini, Referee, Università degli Studi di Modena e Reggio Emilia
Prof. Antonello Astarita, Universita' degli studi di Napoli Federico II
Prof. Flaviana Calignano, Politecnico di Torino
Prof. Diego Giovanni Manfredi, Politecnico di Torino

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The use of Additive Manufacturing (AM) technologies for producing objects for the fashion market is continuously growing, mainly due to the possibility of having virtually infinite creative possibilities. In fact, these techniques allow the production of unconventional shapes, intricate patterns, avant-garde aesthetics, and the exploration of unique shapes and structures that are not achievable through traditional jewellery-making methods. The merging of technology and creativity enables the production of one-of-a-kind jewellery pieces that serve as expressions of individuality and artistic vision, leading to stronger emotional connections between consumers and their accessories towards more consumer-centric and inclusive practices. These lead to a global 3D printed jewellery market size evaluated around USD 8.5 billion in 2023, and a compound annual growth rate of 14% is expected between 2024 and 2030.

In addition to the freedom of design, AM techniques guarantee high-quality, low-cost, lightweight pieces thanks to lattice structures or hollowed parts and the possibility of adopting innovative materials.

Among the different AM technologies, many have been investigated in the jewellery sector; two of these have been studied in the present PhD work: Binder Jetting (BJ) and Lithography-based Metal Manufacturing (LMM). These two were selected considering their ability to print objects with high surface finishing and low roughness, mandatory characteristics for jewels, considering the high comfort level that they must have. Several steps characterise both techniques: a .STL file is printed layer by layer, and green parts are obtained; pieces undergo thermal processes where the binder is removed, and parts are sintered, obtaining the final object characterised by a sensible size reduction.

In this PhD work, all the steps have been considered: at first, different .STL files were designed with Rhinoceros 3D software. In particular, cubes were considered at first, then "The Lotus Flower" and “The Sustainable’s and Beauty” were designed to evaluate the self-support structure, the geometrical freedom, the possibility of integrated parts to avoid welds, the level of detail and dimensional tolerance reachable.

Austenitic stainless steel has been chosen for its diffused use in jewellery due to its corrosion resistance and mechanical properties, resulting in a good scratch resistance of the plate surface.

An analytical method was developed to systematically detect and quantify cross-contamination between metal powders that could affect the mechanical properties, microstructure, and overall integrity of metal parts.

Samples were printed, and then thermal cycles were evaluated. Different atmospheres of debinding and sintering were used for samples deriving from both AM technologies. Air, argon, and vacuum were considered atmospheres for debinding, while hydrogen and vacuum were used for sintering.

Samples printed with LMM showed the best results when debinded in air and then sintered in a reducing atmosphere, particularly when the process is carried out in hydrogen. For samples obtained from BJ, the best results were obtained when debinding and sintering were done in a vacuum atmosphere.

After sintering, the microstructure is fully austenitic and characterised by few pores.

The optimisation of the thermal cycles for both AM technologies led to a carbon content lower than the maximum amount allowed by the material's standard; this highlights that the debinding and sintering cycles are effective, and the polymer degradation occurs correctly. Objects are characterised by microhardness values between 130-150 HV, comparable with those of bulk parts produced with traditional techniques like casting. Moreover, after thermal cycles, samples are characterised by low surface roughness (Ra) on the cubes' sides, lower than a few μm.

The carbon footprint was then evaluated for the final demonstrator to highlight the sustainability of these techniques.