Design, Fabrication and Mechanical Characterization studies on Wire-and-Arc Additively Manufactured (WAAM) diagrid elements

The 4th Industrial Revolution has brought new technologies and materials, such as robotics and 3D printing technologies so that new classes of building constructions and structural forms are ready to be explored. In the last decades, Additive Manufacturing (AM) technologies have been applied in aerospace, automotive and biomedical engineering, but yet to be widely adopted in the construction sector. Nowadays, AM technology in building construction is growing, with the first large-scale outcomes, requiring the customization of conventional automated fabrication technologies. The AM process offers various benefits over conventional manufacturing methods, such as (i) greater structural efficiency, (ii) geometric freedom, (iii) customization, (iv) engineered material properties, (v) reduced material use, (vi) reduced construction waste, (vii) reduced build time and (viii) reduced transportation costs.

Metal Additive Manufacturing plays an important role in the most recent AM research projects. Among different AM technologies, Wire-and-Arc Additive Manufacturing (WAAM) technology proved to be the most suitable for steel large-scale constructions. The high velocity and possibility to realize large-dimension parts, maintaining high structural performances at a relatively good quality of the finishing, confirmed the advantages of applying this technology to realize innovative forms and new shapes for a new generation of structural members. Nevertheless, there are aspects to be explored, the WAAM-produced outcomes present non-negligible geometrical irregularities and anisotropic behavior, which should be characterized in order to perform the structural design of WAAM-produced parts.

The commitment to scientific research is focused on two different printing deposition strategies: (i) the “continuous” printing, consisting in a layer-by-layer deposition, suitable for planar and shell-like geometries; (ii) the “dot-by-dot” printing, consisting in spot-like deposition, whose outcomes are metal bars suitable to realize grid shells and lattice structures.

The study is focused on WAAM-produced steel bars accounting for their structural applications and mechanical characterization. The research period is divided into two parts. The first part was carried out at Technische Universität (TU) Braunschweig with the support of Dr Ing. Harald Kloft within the TRR 277 Additive Manufacturing in Construction (AMC) program, where I developed a novel diagrid column design applying the principles of computational design, ensuring sufficient structural performances under service load. Subsequently, I personally manufactured some prototypes using “dot-by-dot” printing deposition strategy: a scaled column of a 3 m high diagrid column, and a real-scale demonstrator of a 12 m high diagrid column, called WAAMGrid Demonstrator, printing its first 50 cm, due to the manufacturing limits of the UR16e robotic arm. This activity required the know-how of the WAAM printing process parameters with a focus on their influence on the WAAM-produced steel components quality. The adopted WAAM equipment comprises of Universal Robot (UR16e) robotic arm and Fronius TPS 600i PULSE power source.

The second part was carried out at the University of Bologna with Prof. Ing. Tomaso Trombetti as supervisor and Dr Ing. Michele Palermo PhD, Dr Ing. Vittoria Laghi PhD as co-supervisors. My research period was devoted to the structural response of the diagrid column, focusing on the intersections and their influence on specimen behavior. Tensile tests have been performed on as-built steel “dot-by-dot” WAAM crossed bars to characterize their mechanical response with respect to the corresponding straight bars without intersections, taking into consideration the influence of steel bars’ inclination, surface roughness and imperfections.

The diagrid structure presents unbalanced outward forces of the internal actions, due to the absence of horizontal hoops at the level of control cross-section, causing secondary bending moments, which increase the stresses in the diagonal bars. The structural verification proved the better structural performances of the final design realized with an “atomized” hyperboloidal-shaped column with respect to the “atomized” tubular one. The subsequent fabrication pointed out the high role of the adopted printing process parameters in the accuracy of the outcomes. The comparison between WAAM crossed bars and single bars from the same batch shows a slight increase in the average Young’s modulus and a decrease in the average ultimate tensile strength. The strength decreases by increasing the bar’s longitudinal axis inclination.