Microstructural Characterization of Electron Beam Welded Joints between EHEA and Austenitic Stainless Steel

M.Sc. Patrik Jozefovič[1], M.Sc. Jan Rončák[1], M.Sc. Ondřej Ambrož[1], M.Sc. Jan Čermák[1], Ph.D. Šárka Mikmeková[1]

[1]Institute of Scientific Instruments of the Czech Academy of Sciences, Brno, Czech Republic

Background incl. aims

Eutectic high-entropy alloys (EHEAs) have been around for a decade but only recently has become a hot topic in a field of metal alloys . As a subclass of high-entropy alloys (HEAs) enriched with a variety of advantages of eutectic alloys, EHEAs possess superior mechanical properties opening a broad spectrum of possible applications in industry [1]. These alloys are best characterized by the absence of the conventional „strength ductility trade-off“ and remarkable stability over a wide temperature range due to their high-entropy state. Combined with excellent castability, mitigating segregation and shrinkage, they appear to be an ideal candidate for demanding design scenarios such as exposure to elevated temperatures or mechanical stresses commonly encountered in the energy industry [2]. Therefore, they can be seen as a possible competitor for austenitic stainless steels, which possess high ductility with lower tensile strength values and are used for such applications nowadays [3,4]. In this regard , examining the behavior of these specific materials when welded together is prudent, as it can provide valuable insights into their compatibility and suitability for coexistence in industrial applications or utilization in tandem within various industrial sectors. Motivated by the imperative to harness the full potential of advanced materials, our study focuses on the characterization of heterogeneous weld joints between AlCoCrFeNi2.1 EHEA and austenitic steel EN 1.4571, achieved through electron beam welding. The primary objectives of this study are to conduct a comprehensive investigation into the microstructural characteristics of the weld interface and constituent materials. Through a multifaceted approach encompassing various analytical techniques, tests, and image analysis methodologies, our aim is to elucidate as much information as possible, thereby enhancing our understanding of the welding process and the resultant material properties.

Methods

The electron beam welding process was employed to fabricate weld joints between EHEA (AlCoCrFeNi2.1) and austenitic stainless steel (EN 1.4571). Three sets of samples were prepared, each subjected to different welding parameters: beam currents of 13 mA, 17 mA, and 25 mA, with corresponding welding speeds of 10 mm/s, 20 mm/s, 30 mm/s respectively. Prior to welding, samples underwent traditional metallographic procedure. The final preparation step involved electro polishing with parameters meticulously adjusted for optimal results. The microstructure of the weld joints and base materials was examined using multiple microscopy techniques. Light optical microscopy provided a macroscopic view of the weld interface, while confocal scanning laser microscopy offered high-resolution imaging of surface features. Additionally, scanning electron microscopy (SEM) was employed to investigate microstructural details at higher magnifications. On the SEM, Energy Dispersive X-ray Spectroscopy (EDS) was employed for elemental analysis of the weld zones. EDS mapping was conducted to assess the spatial distribution of alloying elements and identify any potential elemental segregation. Furthermore, Electron Backscatter Diffraction (EBSD) was utilized for phase identification and crystallographic analysis of the welds and base materials. Apart from microscopic analysis, mechanical properties of the weld joints were assessed through tensile testing and nanoindentation for hardness evaluation. Tensile tests were conducted to measure the mechanical strength and ductility of the weld joints. On top of that, convolutional neural networks (CNNs) were employed for image analysis to estimate the fractions of BCC and FCC phases present in the microstructure.

Results

All observations were conducted in the same manner to achieve comparable results. The fusion area was examined at three levels: top, middle, and bottom. The top area was defined as 1 mm below the surface of the weld, while the bottom area was 1 mm above the root of the weld, with the middle area positioned equidistantly between these top and bottom regions. Summarizing the results, in all scenarios, EDX line scans along the axis of the weld showed minimal fluctuations in chemical composition. Conversely, significant chemical composition changes were observed when examining lines across the weld, particularly at the fusion zone boundaries, while the elemental levels remained stable after the transition. This phenomenon was consistent at every level of observation, with increasing fluctuations in the middle and bottom areas. It is also noteworthy that carbon nitrides from EN 1.4571 were observed across various regions of the fusion zone, contributing to the complexity of the microstructure and hindering the diffusion of chromium due to carbon and nitrogen binding. From a phase perspective, the entire fusion area exhibited a face-centered cubic (FCC) dendritic structure with interdendritic space formed by body-centered cubic (BCC) precipitates, resembling the EHEA-like phase map, which consists of FCC and BCC lamellas, while EN 1.4571, consistent with its inherent properties, maintained an FCC phase. Moreover, BCC stripes were predominantly observed at the interface between EHEA and the fusion zone, likely as a product of segregation. Conversely, the transition between EN 1.4571 and the fusion zone primarily consisted of an FCC phase with smaller BCC precipitates appearing deeper into the fusion zone. This observation is further supported by the grain orientation map, where grains adjacent to EN 1.4571 maintained larger sizes comparable to the base material matrix on this side of the weld, while also exhibiting almost identical orientation to the nearest grains of the base material.

As one delves deeper into the fusion zone, the relative grain size diminishes, and their orientation becomes more random, coinciding with the appearance of precipitates. These precipitates, besides exhibiting a BCC phase, displayed an inner structure that was analyzed, albeit yielding no further discoveries.

Conclusion

Optimal parameters for welding EHEA together with EN1.4571, as well as metallographic preparation of such welds, were established. The microstructure was subsequently observed and analyzed using a spectrum of different techniques, offering profound insights into both the welding process and the resultant structure. Our observations unveiled a finely nuanced and complex microstructure within the fusion zone, adorned with small BCC precipitates ranging from a few to tens of micrometres. Additionally, EBSD analysis underscored the pivotal role of the weld interface in shaping the evolution of the microstructure. Continued analysis, including the exploration of AI-powered image analysis techniques for fusion zone estimation, is warranted to deepen our understanding and uncover further intricacies.

Graphic:

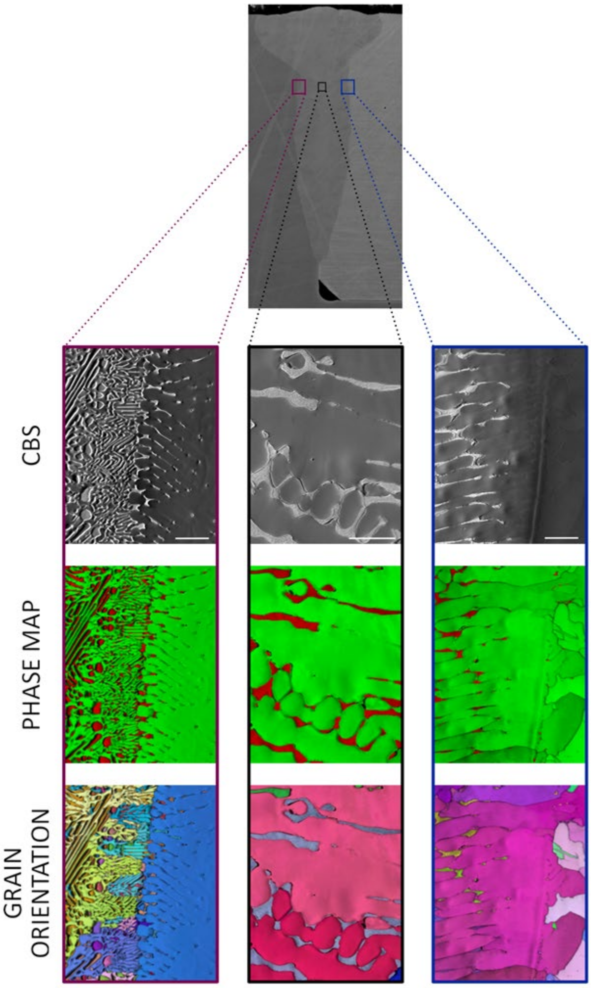

Fig. 1 Micrographs of different areas with corresponding phase and grain orientation maps

Keywords:

EHEA, austenitic-stainless-steel, electron-beam-welding, microstructure-analysis, ML

Reference:

[1] Shafiei, A. Design of Eutectic High Entropy Alloys. Metall Mater Trans A 53, 4349–4361 (2022)
[2] Jiao, W., Wang, Z., Guo, S., Lu, Y.. Eutectic High-Entropy Alloys (2022)

[3] Su, K., Nong, ZS., Gu, ZH. et al. Microstructural and Mechanical Properties of AlCoCrFeNi2.1 Alloy Welded Joint by Vacuum EBW. JOM 75, 2721–2730 (2023).
[4] Zhang, X., Liu, L., Yao, K. et al. The evolution of eutectic microstructure and mechanical properties of AlxCoCrFeNi2.1 high-entropy alloys. Journal of Materials Research 37, 2082–2092 (2022)

The authors acknowledge that the reserch was funded from the Lumina Quaeruntur fellowship established by the Academy Council of the Czech Academy of Sciences, award for prospective researchers recieved by Dr. Mikmeková.