学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　博士（工学）　氏名　SUN Haotian

学 位 論 文 題 名

Research and development of diffusion bonding between high entropy alloys and stainless steel for nuclear application

(原子力用ハイエントロピー合金とステンレス鋼の拡散接合研究)

To meet rapidly increasing global energy needs, safe, reliable, and economic operation of advanced fission and eventually fusion power plants is generally considered an important element of a lower carbon energy future. In the application of nuclear power plant and other fields, structural parts are mostly composed of multiple parts rather than a single part. Therefore, joining technology, as a processing method that can assemble parts into an integral structure, plays a vital role in promoting the engineering application of high entropy alloys (HEAs). However, compared with the studies on the design and performance of HEAs, the research on the joining of HEAs is relatively insufficient. Thus, suitable joining technologies for HEAs are needed to enlarge the application range for HEAs. Diffusion bonding has been applied in the field of nuclear power, such as first wall, which are manufactured with steel due to its outstanding oxidation resistance, mechanical properties and corrosion resistance at high temperatures. As a new material, HEAs also might be used in high temperature parts in the field of nuclear power. Therefore, it is necessary to investigate the diffusion bonding of HEAs to steels for further promoting the application of HEAs in nuclear power plant.

Firstly, equiatomic CoCrNi-based concentrated solid solution alloys (CSSAs) system (CoCrFeNiMn, CoCrFeNi, and CoCrNi) were successfully joined to 316 stainless steels by SPS diffusion bonding, and the effect of bonding temperature and concentration on diffusion behavior and tensile property of bonded joints were investigated. The tensile strength of the CSSAs/316SS joints were gradually increased with increasing bonding temperature. In addition, the tensile strength of the joints bonded at $0.8T_m$ were all exceeded 80% of that in 316SS. Meanwhile, the bonding at $0.8T_m$ seemed to have sufficient diffusion and grain growth at the interface, resulted in the disappearance of voids and the increase in strength of joint. Furthermore, it suggests that the continuous FCC solid solution structure was generated in the diffusion zone, which was beneficial to the increase of tensile property in joints.

Secondly, this study explored the diffusion bonding of $Cr_{0.8}$FeMnNi medium entropy alloy to 316SS with and without a Ni interlayer using spark plasma sintering. Direct bonding led to the formation of Cr_2O_3 and Mn_3O_4 oxides at the interface, resulting in stress concentration and reduced tensile strength.

However, the introduction of a Ni interlayer effectively reduced oxide size and improved mechanical properties by accelerating diffusion and relieving stress concentrations. Optimal joints were achieved at 820 ℃ / 60 min / 25 MPa, producing joints with tensile strength and elongation comparable to 316SS. Furthermore, diffusion behavior, growth kinetics of diffusion layers, and activation energy of diffusion in various atoms and layers were analyzed. The activation energy of each element in the joints with Ni interlayer was decreased compared to direct diffusion bonding.

Thirdly, this study focuses on analyzing the effect of dislocations on diffusion behavior in diffusion bonded $Cr_{0.8}FeMn_{1.3}Ni_{1.3}$ HEA/316SS joints. The joints cold-worked with different deformation rate and 316 stainless steels had similar grain sizes, but the dislocation density increased with the increase in deformation rate. In addition, Mn-O oxides and Cr-Mn-O oxides were recognized at the interface. Through line scanning of the interface, it was found that the diffusion distance of atoms trough the joint increased with the increase in deformation rate, which probably due to the increase in dislocations as diffusion channels. As the secondary deformation rate increased from 0% to 20%, the diffusion distance through the joint increased from 4.80 microns to 8.31 microns. This result could suggest that the diffusion ability of atoms within the crystal structure may be enhanced in case a significant dislocation density was present in the HEA base metal, resulting in increased diffusion distances and higher tensile strength in diffusion bonded joints.

The HEA/316SS diffusion bonded joints shows good joining property, which could be candidate materials for advanced reactors.