

Abstract

Metals and their alloys have long served as foundational materials across various industries due to their versatile properties. With advancing technology, the need to enhance and tailor the properties of metals and alloys, has become increasingly crucial to satisfy modern application requirements. High entropy alloys (HEAs) represent a new class of metallic materials characterized by their unique multi-element compositions, providing an expansive range of compositional possibilities and enabling unprecedented opportunities in materials science. HEAs have demonstrated remarkable properties across diverse fields, including outstanding strength, toughness, corrosion resistance, and thermal stability. Due to their superior mechanical and thermal characteristics, HEAs show significant potential as alternatives to conventional structural materials like steel, titanium and Ni super alloys. However, the underlying mechanisms responsible for these exceptional attributes are not yet fully understood in current literature, inspiring researchers to explore the mechanisms behind their unique behavior and to develop methods that would enhance their properties and, hence, broaden their applicability. Among the most promising are CoCrFeNi-based HEAs, which exhibit desirable mechanical properties, particularly when alloyed with Al and Ti. These elements have been shown to improve precipitation strengthening, further enhancing mechanical performance. However, the deformation mechanisms in non-equiatomic CoCrFeNi HEAs with Al and Ti additions, particularly the effects of aging and compositional variations on deformation, remain largely unexplored. This thesis presents a systematic investigation into the deformation behavior of $\text{Al}_x\text{Co}_{1.5}\text{CrFeNi}_{1.5}\text{Ti}_y$ (where $x + y = 0.5$, in atomic ratio and $x = 0, 0.2, 0.3, 0.5$) HEAs, with a specific focus on understanding how alloy composition, aging, and microstructure affect their tensile, strain-hardening and hot deformation properties.

In the initial stages of this study, the four HEA compositions were subjected to solutionizing and peak aging treatments. Tensile tests on both solutionized and peak-aged samples were used to derive stress-strain and strain hardening curves. An increase in Ti content and aging notably enhanced the strength and elevated the strain hardening rate of each alloy. Fractographic analysis revealed that the alloy with highest Ti content has the highest tendency for brittle fractures, showing cleavage features, while the alloy with lowest Ti content retains the most ductile characteristics.

Further, high-resolution transmission electron microscopy was employed to examine the microstructure in deformed regions after tensile tests. The study found that Ti additions increased the work-hardening rate and affected deformation by inducing planar slip and forming Taylor lattices and stacking faults. TEM analysis further confirmed a shift in deformation mechanism from wavy to planar slip as Ti content increased. The precipitation hardening mechanisms varied in various age hardened alloys, with B2 precipitates enhancing hardening through Orowan looping, whereas L1₂ precipitates primarily caused hardening through shearing by partial dislocations and the interaction of stacking faults forming Lomer–Cottrell (LC) locks. The deformation substructure, specifically Taylor lattices, were observed exclusively in the solutionized condition, with their formation significantly reduced upon aging, thereby absent in peak-aged conditions. Deformation in all the alloys primarily occurred via planar slip on {111} planes.

The alloy Al_{0.3}Co_{1.5}CrFeNi_{1.5}Ti_{0.2} (Al03Ti02), after aging, emerged as the only alloy among the four to exhibit two types of precipitates in peak-aged condition, achieving the highest yield strength increase while maintaining considerable ductility. Peak aging after 120 hours produced both B2 and L1₂ precipitates, resulting in a ~187% increase in yield strength, and a ~214% rise in hardness compared to the solutionized state. Hence, the thesis presents findings from a detailed analysis of the mechanical properties, aging behavior, and strain hardening

mechanisms of Al_{0.3}Ti_{0.2} alloy, and was selected as a primary focus for further studies on hot deformation due to its intermediate Ti content and balanced mechanical properties.

Henceforth, the thesis explores the hot deformation behavior of Al_{0.3}Ti_{0.2} alloy at temperatures from 923 K (650 °C) to 1,373 K (1100 °C) and strain rates of 10⁻³ to 1 s⁻¹ using a Gleeble® 3800 thermomechanical simulator. Constitutive modeling and processing maps, based on the Dynamic Materials Model, were developed to identify optimal processing conditions and safe work domains. At 923 K, the power-law breakdown was observed, and flow curves showed no softening. While the highest hot workability efficiency (~34%) was found in the 1,300 K (1027 °C) temperature range at strain rates between 0.03 s⁻¹ and 1 s⁻¹, the unstable region predominantly occurred within the strain rate range of 0.01 s⁻¹ to 1 s⁻¹ and the temperature range of 923 K (650 °C) to 1,165 K (892 °C), characterized by the formation of voids and cracks. Dislocation climb and discontinuous dynamic recrystallization were identified as the primary deformation mechanisms.

Overall, this thesis provides a comprehensive understanding of how alloying, aging, and microstructure influence the mechanical and deformation behavior of Al_xCo_{1.5}CrFeNi_{1.5}Ti_y HEAs, with detailed insights into strain hardening and hot deformation mechanisms. These findings underscore the critical role of precipitates, dislocation substructures, and microstructural evolution, and open pathways for optimizing the properties of HEAs through controlled alloying and heat treatment techniques. The outcomes contribute valuable knowledge for developing advanced high-performance materials suitable for demanding structural applications. Future research could focus on exploring the effects of additional alloying elements such as Mo, Nb, and C in non-equiatomic CoCrFeNi systems, as well as refining grain size through thermomechanical processing, to enhance strength and provide deeper insight into microstructural evolution and deformation mechanisms.