The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 32, Pages 483-487

IConTES 2024: International Conference on Technology, Engineering and Science

Magnetic Control of Phase Evolution in Titanium-Based Alloys Synthesized by Ball Milling

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Abstract: Nanostructured TiAlV alloys were synthesized from pure titanium, aluminum, and vanadium powders using the mechanical alloying technique in a high-energy planetary ball mill. The magnetic behavior, morphology, and microstructural properties were examined using a Vibrating Sample Magnetometer (VSM), Scanning Electron Microscope (SEM), and X-ray Diffraction (XRD), respectively. The crystallite size decreased from 48.73 nm to 9.38 nm, while lattice strain increased from 0.15% to about 0.81% after 60 hours of grinding. X-ray diffraction confirmed the formation of new phases during the grinding process. Magnetic non-destructive testing revealed that the nanocrystalline TiAlV alloy contains magnetic particles whose properties vary over time periods, attributed to the reduction in crystallite size of these particles due to collisions with the milling balls. NDT by magnetic measurement confirmed that the state of the nanocrystalline alloy can be controlled using a vibrating sample magnetometer.

Keyword: Nanostructured Tialv Alloys, Mechanical Alloying, NDT, Magnetic Measurement.

Introduction

Nanocrystalline alloys, synthesized through various methods including powder metallurgy, offer significant advantages in engineering applications. Non-destructive techniques play a crucial role in controlling nanocrystalline materials for industrial use, as they provide insights into performance evaluation without damaging the material (Abada et al., 2020; Yang et al., 2016). Titanium alloys, known for their exceptional properties, are extensively used in aerospace manufacturing despite being non-magnetic and exhibiting poor tribological behavior. Among these, TiAlV alloys are prominent, comprising α and β phases that are stable at low temperatures. However, limited research exists on the production of nanocrystalline titanium alloys via mechanical milling, a technique capable of producing nanometric structures (Metidji et al., 2020;Ter Haar et al., 2018; Daswa et al., 2018). In this study, nanocrystalline TiAlV alloy was synthesized using mechanical milling, which relies on welding and fracture phenomena caused by mechanical impacts between powder particles, grinding balls, and the jar wall.

The research aims to evaluate the alloy using magnetic non-destructive testing to identify impurities generated during grinding and their effects on different properties. The approach involves using a vibrating sample magnetometer for magnetic measurements to monitor the progression of the nanocrystalline alloy and detect defects introduced during mechanical grinding.

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

Materials and Experimental Procedure

High-purity Ti, Al, and V powders were used as starting materials, with elemental compositions of 99.9%, 99.7%, and 99.9%, respectively. These powders were subjected to grinding in a high-energy planetary ball mill at room temperature and under a controlled atmosphere, using hardened Cr steel balls (20 mm diameter) at a speed of 300 rpm. A ball-to-powder weight ratio of 12:1 was employed, and the grinding time ranged from 0 to 60 hours. This process aims to produce TiAlV alloys and reduce grain sizes through severe plastic deformation. The magnetic non-destructive testing was conducted using vibrating sample magnetometers (EV9). Morphological analysis of the powders was carried out using a scanning electron microscope (Gemini SEM 300) equipped with an energy-dispersive X-ray analyzer (EDS).

Results and Discussion

Magnetic Measurements

Figure 1 depicts the relationship between magnetization and magnetic field strength at room temperature for the nanocrystalline TiAlV alloy, illustrating the impact of ball collisions during milling. Initially, the elemental powder is non-magnetic. However, after undergoing ball milling, the samples exhibit a significant increase in coercivity (Hc) and a reduction in saturation magnetization. This change in magnetic behavior indicates a transformation in the alloy's microstructure. The increase in coercivity suggests an enhancement in the material's resistance to demagnetization, which can be attributed to the refinement of grain sizes and the introduction of defects induced by the milling process. The decrease in saturation magnetization indicates a reduction in the alignment of magnetic moments within the material, possibly due to the disruption of the crystalline structure caused by severe plastic deformation during milling. These findings highlight the role of mechanical grinding in altering the magnetic properties of the nanocrystalline TiAlV alloy (Zhao et al., 2010; López-Dominguez et al., 2001; Getzlaff et al., 2008; Foner et al.,1996).

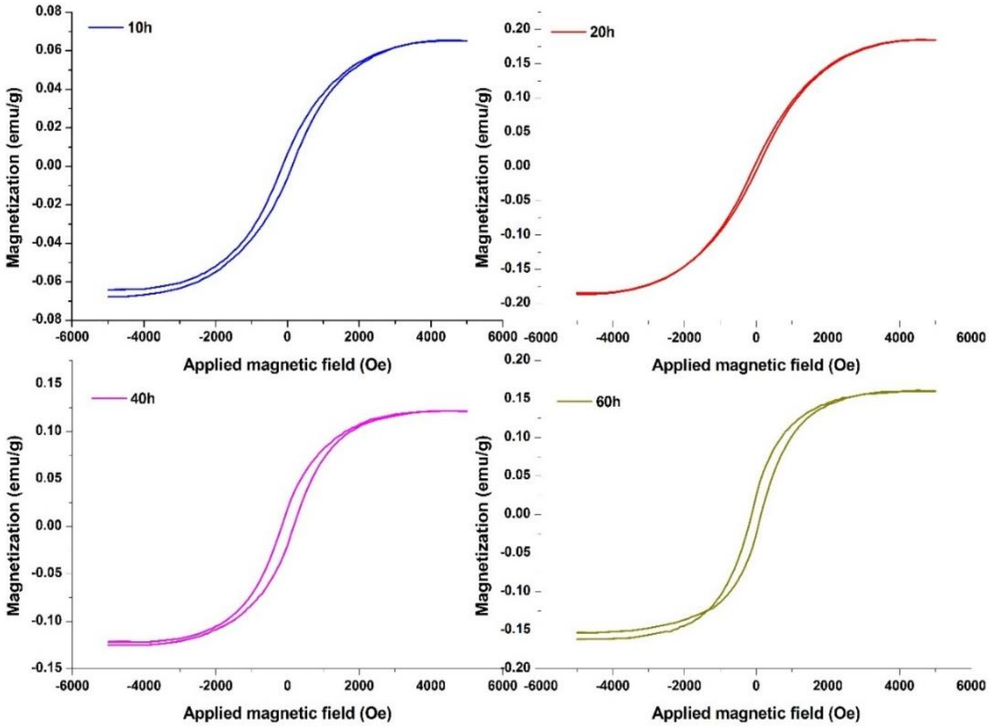

Figure 1. Hysteresis curve of nanostructured TiAlV alloy grinded for different durations

Figure 2 illustrates the variation in various magnetic parameters during mechanical alloying. The coercivity shows significant variation throughout the milling process, attributed to the reduction in crystallite size of iron particles worn off from the milling balls due to repeated ball collisions. The Ms is a key characteristic of magnetic materials, influenced by the chemical composition of the local atomic environment and their electronic structures. The presence of iron particles from the milling balls, mixed with Ti(Al) and Ti(Al,V) during milling, results in a non-saturating magnetic behavior.

This behavior suggests that the introduction of iron from the milling balls alters the local magnetic environment, affecting the alignment of magnetic moments within the material. This alteration is likely due to the introduction of defects and changes in the alloy's microstructure caused by the milling process (El-Alaily et al., 2015; Babu et al., 2020).

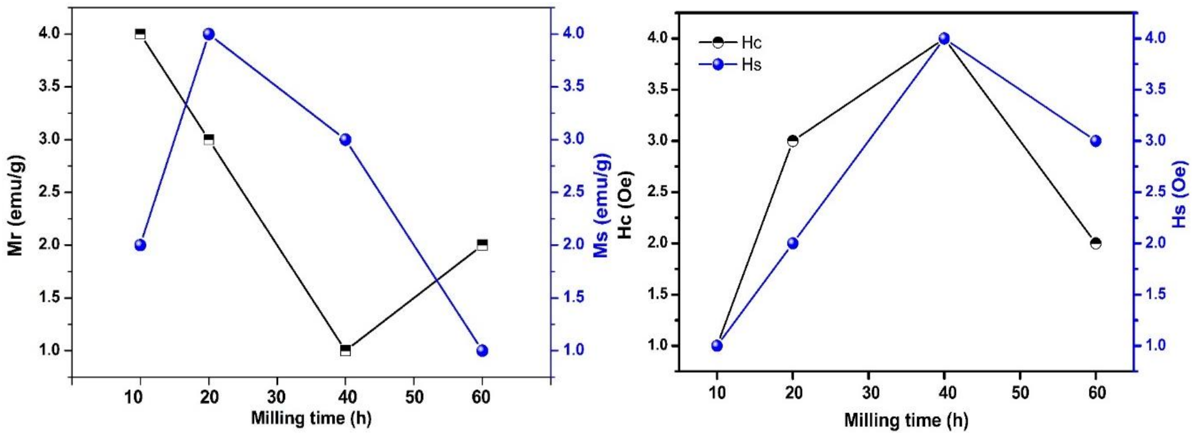

Figure 2. Different magnetic parameters as function of milling time

Morphology

Figure 3 illustrates the morphological changes in nanocrystalline TiAlV alloy at different grinding times (0, 20, and 40 hours), indicating significant variations in particle size, shape, and nature with increasing grinding time. Initially, Ti, Al, and V particles exhibit irregular shapes and sizes.

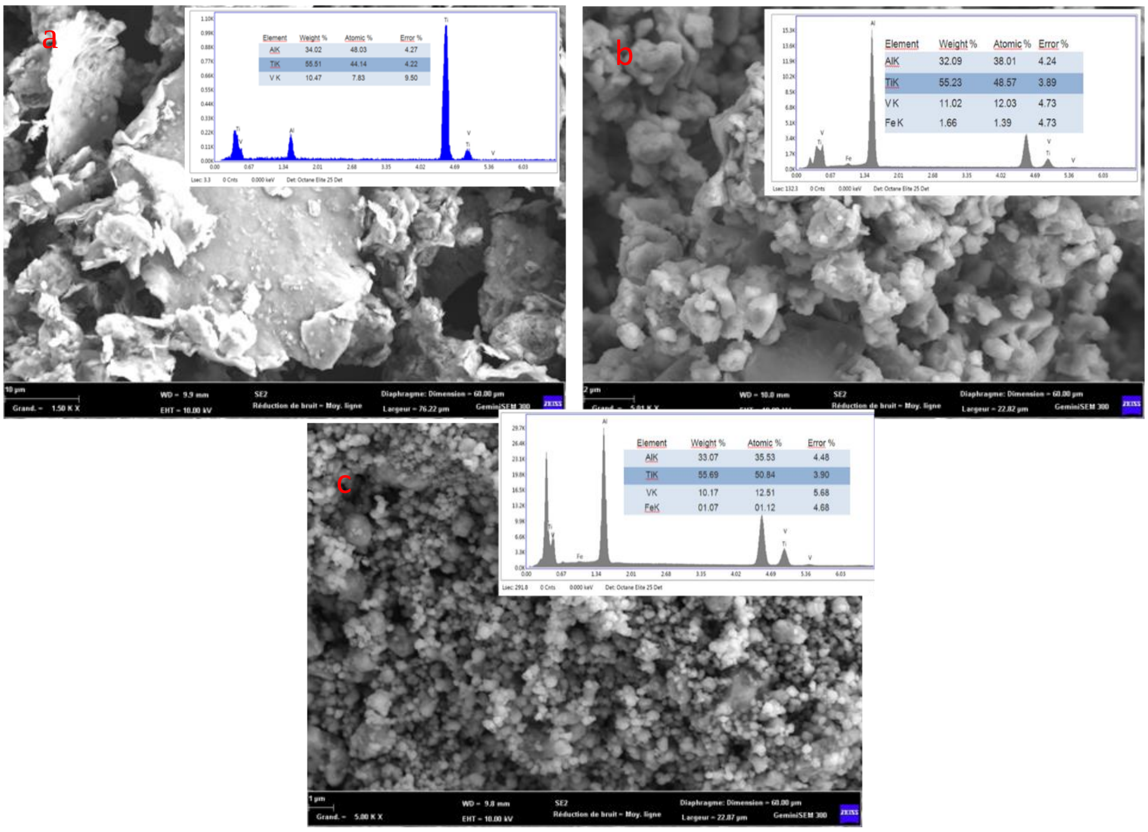

Figure 3. SEM micrographs and EDS analysis of nanostructured TiAlV alloys grinded for different duration: (a) 0 h, (b) 20 h, and (f) 40 h.

After 20 hours, particles become spherical and irregularly shaped, with an average size of 5-10 µm, attributed to repeated welding and fracturing during mechanical alloying. Further grinding reduces particle size, reaching a more homogeneous distribution after 40 hours, where fracturing and cold welding processes are in equilibrium. EDS micrographs reveal that before grinding, Ti, Al, and V elements are not homogeneously dispersed, with no contamination. During grinding, the element distribution becomes uniform, with some iron contamination from worn grinding balls, indicating the formation of TiAlV alloy powder. After 40 hours, particles show homogeneous dispersion, with some iron residue from grinding ball collisions (Dilmi et al., 2020; Younes et al., 2021; Shah et al., 2016; Mahboubi et al., 2012).

Conclusion

The synthesis of nanocrystalline TiAlV alloy through high-energy ball grinding for varying durations has been successfully achieved, revealing several stages in its formation. Initially, the elemental powders are non-magnetic. However, during milling, the coercivity varies, primarily attributed to the reduction in crystallite size of iron particles worn off from the milling balls due to repeated ball collisions. EDS analysis of the nanocrystalline TiAlV alloy after mechanical grinding indicates the presence of iron contamination from the grinding balls, confirming the magnetic behavior observed in the magnetic measurement results. This contamination corroborates the impact of ball collision on the alloy's magnetic properties. The study highlights the effectiveness of high-energy ball grinding in synthesizing nanocrystalline TiAlV alloy and underscores the importance of understanding the role of milling parameters in tailoring the alloy's properties.

Recommendations

Future research should focus on optimizing milling parameters, such as duration and ball material, to better control crystallite size and minimize iron contamination, which affects the TiAlV alloy’s magnetic properties. Using alternative grinding media or protective coatings on milling balls could further reduce contamination, allowing for more accurate magnetic measurements. Advanced characterization techniques would deepen understanding of milling effects, while testing the alloy’s magnetic behavior in varied conditions would help evaluate its suitability for targeted applications, enhancing its potential as a tailored nanocrystalline material for industrial use.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as a poster presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 14-17, 2024.

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To cite this article:

Abada, A., Younes, A., & Amraoui, R., (2024). Magnetic control of phase evolution in titanium-based alloys synthesized by ball milling. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 32,* 483-487.