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Mechanical Properties and Fractographic Analysis of Austenitic Stainless Steel at Sub-Zero Temperatures

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INTRODUCTION & AIM

The global transition to sustainable energy has intensified the search for efficient, safe, and cost-effective materials for hydrogen storage and containment. As a clean energy carrier, hydrogen offers high gravimetric energy density and the potential to reduce greenhouse gas emissions when coupled with renewable technologies. However, widespread adoption remains limited by the lack of materials that can absorb, retain, and release hydrogen safely under practical conditions. Among structural alloys, austenitic stainless steels—particularly AISI 304—are of interest for their corrosion resistance, strength, and availability. Their face-centered cubic (FCC) structure enables hydrogen solubility while minimizing embrittlement compared to ferritic or martensitic grades. Furthermore, microstructural or surface modifications such as cold working, passivation, and alloying with Mo or Ti can enhance hydrogen absorption and diffusion. This study investigates the cryogenic mechanical properties and fracture behaviour of AISI 304 stainless steel to assess its performance and reliability in hydrogen storage and transport environments.

METHOD

Cylindrical AISI 304 stainless steel specimens (8 mm diameter, 50 mm gauge length) were prepared using standard metallurgical methods. Tensile tests were conducted on a Z100 Zwick/Roell universal testing machine with a liquid nitrogen cooling chamber to achieve cryogenic conditions. Tests at room and sub-zero temperatures were performed under controlled strain rates, with temperature stability ensured by circulating nitrogen gas and monitored via a K-type thermocouple on the gauge section. Post-test fracture surfaces were examined by scanning electron microscopy (SEM) to assess deformation and fracture mechanisms.

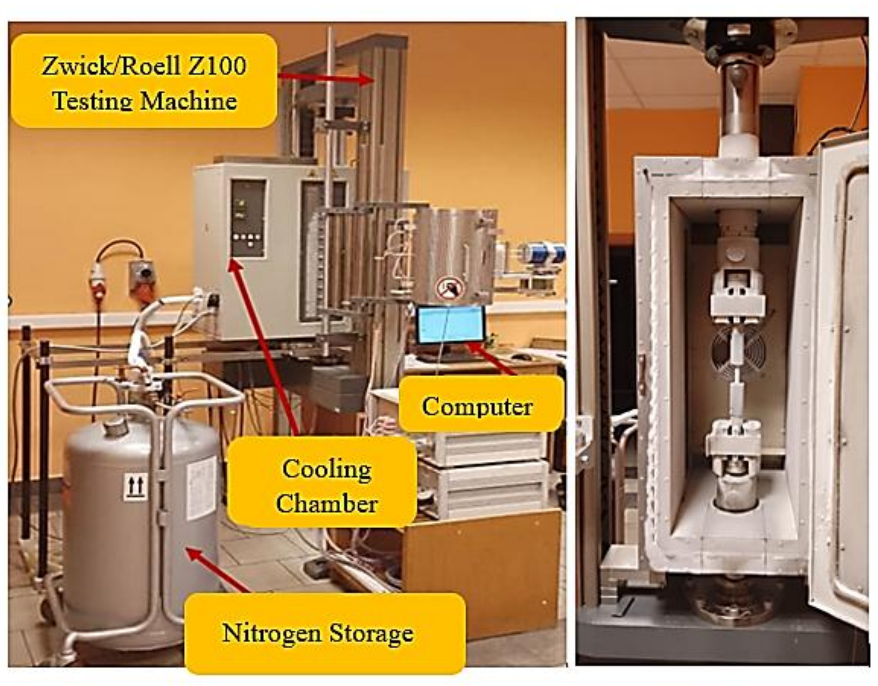

Figure 1. A cryogenic tensile testing system equipped with a cooling chamber to maintain the specimen at low temperatures..

RESULTS & DISCUSSION

This study investigated the cryogenic mechanical behaviour and fracture characteristics of AISI 304 stainless steel under varying temperatures and strain rates. Strength increased markedly with decreasing temperature due to reduced dislocation mobility and strain-induced martensite formation, while ductility showed a moderate decline, reflecting the typical strength–ductility trade-off. The fracture mode transitioned from ductile microvoid coalescence to mixed ductile–cleavage features at lower temperatures, though the material maintained good toughness and structural integrity. Overall, AISI 304 exhibited excellent mechanical reliability under cryogenic conditions, confirming its suitability for hydrogen storage and low-temperature energy applications.

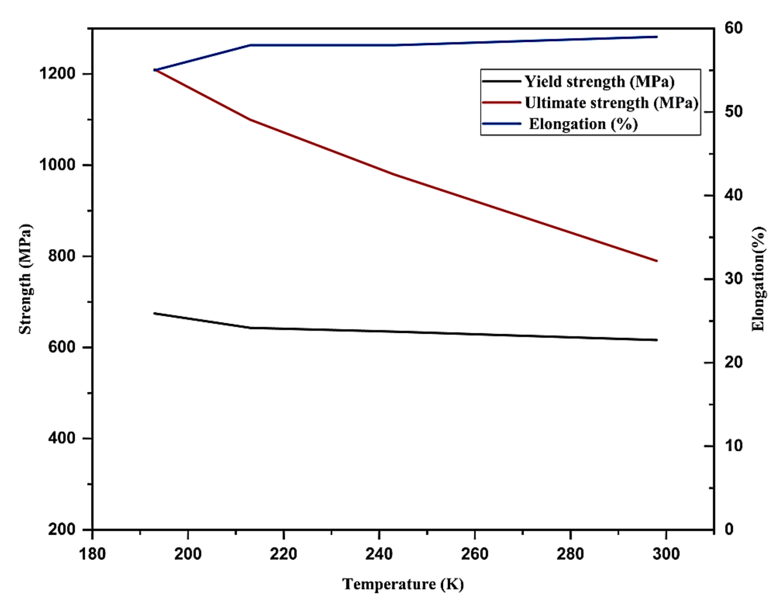

Figure 2. Temperature-dependent cryogenic properties of AISI 304 austenitic stainless steel.

CONCLUSION

This study examined the cryogenic mechanical behaviour and fracture characteristics of AISI 304 stainless steel under different temperatures and strain rates. Strength increased notably with decreasing temperature due to reduced dislocation mobility and strain-induced martensite formation, while ductility declined moderately, showing a typical strength–ductility trade-off. Fracture mode shifted from ductile microvoid coalescence to mixed ductile–cleavage features at low temperatures, yet the material retained good toughness and structural integrity. Overall, AISI 304 demonstrated excellent mechanical reliability under cryogenic conditions, confirming its suitability for hydrogen storage and low-temperature energy applications..

FUTURE WORK / REFERENCES

Future studies should examine hydrogen charging effects on AISI 304's microstructure and mechanics under cryogenic conditions. Advanced in-situ characterization can clarify hydrogen-induced transformations and deformation behaviour. Research on alloying, surface treatments, and processing effects, as well as testing welded or additively manufactured components, will further optimize AISI 304 for hydrogen storage and low-temperature applications.