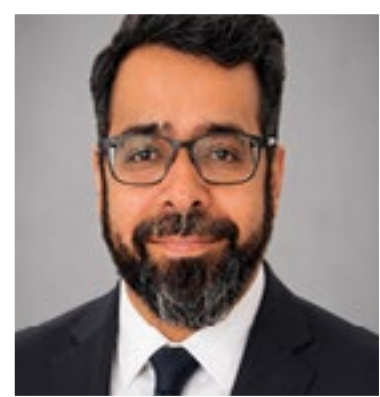




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CASE STUDY

The Challenge

High-strength near-beta titanium alloys such as Ti-5553 are used in demanding aerospace applications, but their fracture behaviour is difficult to predict because it is governed by complex interactions between microstructure, interfaces, grain morphology, and loading state. Conventional testing can measure strength or toughness, but it does not explain why one microstructure performs better than another, or how processing routes should be adjusted to improve damage tolerance.

A key industrial challenge is that failure can initiate at the microscale through void nucleation and localisation around alpha/beta interfaces, while the final structural response depends on larger-scale features such as elongated beta grain alignment relative to the crack path. This means that both microscale interface mechanics and mesoscale microstructural morphology must be understood together.

The project therefore addressed two linked questions:

- (1) how stress state, alpha/beta interfacial mechanics, crystal orientation, and fraction influence local damage initiation in Ti-5553; and
- (2) how elongated beta grain alignment affects crack-tip localisation, crack driving force, and fracture toughness under realistic compact tension loading. Together, these questions target a major gap in current design practice: the lack of predictive tools linking thermomechanical processing, microstructure, and fracture performance in aerospace titanium alloys.

Innovation

This project developed a multiscale, microstructure-informed modelling framework for Ti-5553, combining experimental characterisation with crystal plasticity finite element modelling.

The first part of the work established a mechanistic understanding of damage at the microscale by building EBSD-informed representative volume elements and systematically varying stress triaxiality, Lode parameter, alpha/beta interface geometry, Burgers orientation relationship (BOR) variants, crystal orientation, and alpha-phase volume fraction. This enabled prediction of where damage would nucleate and how it would evolve under different loading conditions.

The second part extended this insight to a fracture setting by embedding a microstructure-resolved alpha/beta submodel at the crack tip of a compact tension specimen. This made it possible to study how beta colony/grain alignment relative to loading and crack direction changes damage localisation, fracture process zone development, J-integral response, and toughness. The work showed that fracture resistance is governed not simply by how much damage forms, but by how damage is distributed or localised ahead of the crack tip. Together, the two studies create a physically grounded framework that links processing-sensitive microstructure to predictive fracture performance.

Result

The project delivered a number of important findings. From the microscale study, it was shown that damage resistance in Ti-5553 depends strongly on loading state and interface mechanics. Around 10% fraction was beneficial at moderate triaxiality, whereas ~5% performed better at higher triaxiality. The work also showed that crystallographic compatibility across alpha/beta interfaces and BOR variant selection directly influence stress concentration, slip transfer, and void nucleation, with some interface/crystal combinations delaying localisation and others accelerating damage. SEM observations near fracture surfaces supported the model predictions of voiding around alpha regions and alpha/beta interfaces. From the fracture/submodelling study, it was shown that mesoscale beta grain alignment has a dominant influence on crack-tip behaviour. The morphology with elongated beta grains aligned favourably produced

more distributed damage, lower failed volume fraction, lower localisation, and a more stable crack driving force (J) response. The unfavourable morphology produced stronger localisation and lower toughness. Experimentally measured fracture toughness increased from 43.10 MPa√m to 51.69 MPa√m, i.e. by about 20%, depending on beta grain alignment.

Taken together, the results show that both microscale interfacial mechanics and mesoscale beta alignment must be controlled to improve fracture performance.

Impact

The project provides a clear route from materials processing to structural performance. It shows that fracture performance in Ti-5553 can be improved not only by changing alloy chemistry, but by controlling:

- alpha fraction
- alpha/beta interface characteristics
- beta colony/grain alignment relative to loading
- processing routes that influence these features

How could this change the sector?

For aerospace manufacturers and forming specialists, this means thermomechanical routes such as forging, rolling, and heat treatment can be designed more intelligently to produce microstructures that resist damage localisation and crack growth. Instead of relying mainly on costly experimental iteration, the sector can use predictive modelling to identify processing windows that lead to better damage tolerance.

What's the potential?

The framework supports:

- faster materials and process optimisation
- reduced testing burden
- improved reliability of safety-critical titanium components
- more confident qualification of processing routes
- future digital-twin and AI-enabled materials design approaches

In practical terms, the project helps shift titanium component development from empirical trial-and-error towards microstructure-informed predictive engineering, with direct relevance to aerospace and other high-value manufacturing sectors.

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“Amir’s Research in Residence fellowship has been a successful collaboration between the University of Aberdeen and the Advanced Forming Research Centre (AFRC), bringing advanced modelling expertise to an important manufacturing challenge. By combining experimental characterisation with microstructure-informed modelling, the project has deepened our understanding of how titanium alloy microstructures influence damage and fracture resistance. For the AFRC, this provides a valuable foundation for linking forging and heat-treatment routes to component performance, supporting our ambition to move towards more predictive, materials-informed process design. The fellowship has also strengthened knowledge exchange between our teams and established a strong basis for further collaborative research.”
- Prof. Salaheddin Rahimi, Chief Engineer at the AFRC, University of Strathclyde.

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“This work shows how microstructure-sensitive modelling can connect processing, interfaces, and crack-tip behaviour, giving industry a more predictive route to designing tougher and more reliable titanium components.”