Analysis and Comparison of Ti- 6Al- 4V Billet for Forging Stock

PURDUE MATERIALS ENGINEERING

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Alcoa, Inc. has asked our team at Purdue to analyze and compare Ti-6Al-4V billet forging stock of three titanium suppliers. Alcoa wants their forged final product made of Ti-6Al-4V to match their customers' needs. Our senior design team needs to characterize the billets from three different suppliers in order to ensure the best suited product Alcoa will supply. Our goal is to rank billet quality based on the results of a quantitative comparative analysis of the three titanium suppliers that compares the mechanical properties and microstructure of each supplier's billets. In order to achieve the goal, we will analyze and compare microstructure and mechanical properties of each billet supplier to determine what causes the property differences.

This work is sponsored by Alcoa, Inc,, Cleveland, OH

ALCOA

Ingot → Forging Operations → Annealing Process → Billet

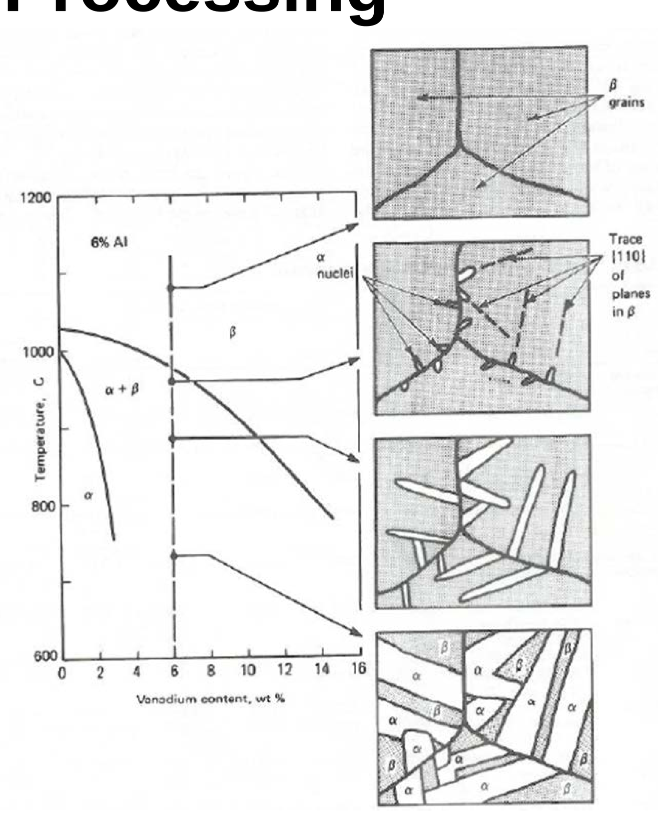
Project Background

- Ti- 6Al- 4V is uniquely suited for its application in aircraft engines due to its excellent strength and ductility characteristics.
- The high strength to low weight ratio and excellent corrosion resistance properties allows Ti 6-4 to perform with a high reliability in its application.
- Although Ti 6-4 is reliable, Alcoa has found differences in the microstructure of their final product based on different suppliers' metal.
- Comparing the three different suppliers' billets, prior to being forged, can give Alcoa insight in order to produce the best quality final forged product based on customers' needs

Experimental Procedure

In the billetizing process, as-cast titanium is mechanically worked and thermally treated to form billets. Each supplier has a different billetizing process which results in various microstructures and properties. Alcoa's billetizing process is seen in the flow diagram above. Therefore, microstructure and mechanical properties will be analyzed for each billet. The microstructure portion of the test plan is to analyze morphology, grain size, and structure. Mechanical tests will include tensile, fracture toughness, and fatigue crack growth rate tests.

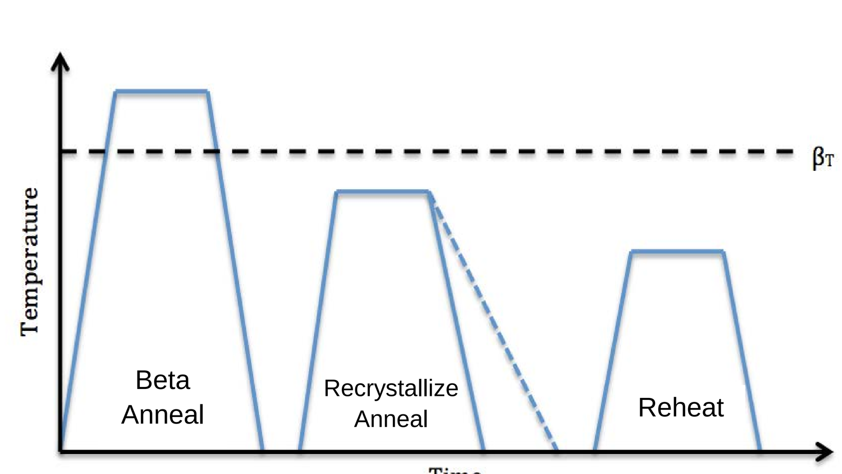
Processing



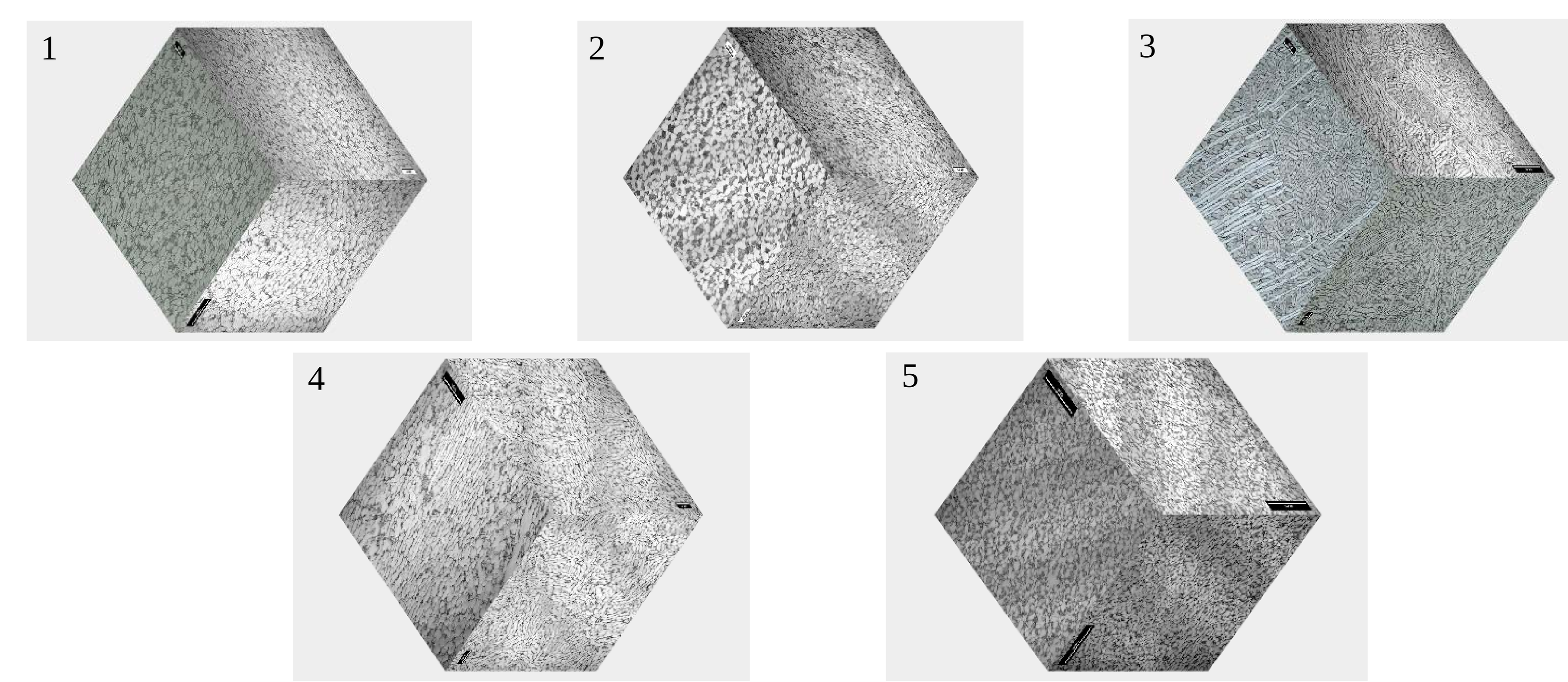
Ti- 6Al- 4V is considered to be alpha-beta titanium, meaning both the alpha and beta phase are present in the alloy. In the annealing process, the alpha phase is formed by cooling the beta phase titanium. Plates of alpha phase titanium begin to form at the beta-beta grain boundaries. The alpha plates then nucleate into colonies. Plate formation is shown in the schematic.

The annealing process continues when the alpha plates form a basket-weave structure upon cooling. The thickness of each alpha plate is dependent on the cooling rate. The part is heated to just below the beta transus temperature where the individual plates fuse together to form equiaxed alpha grains.

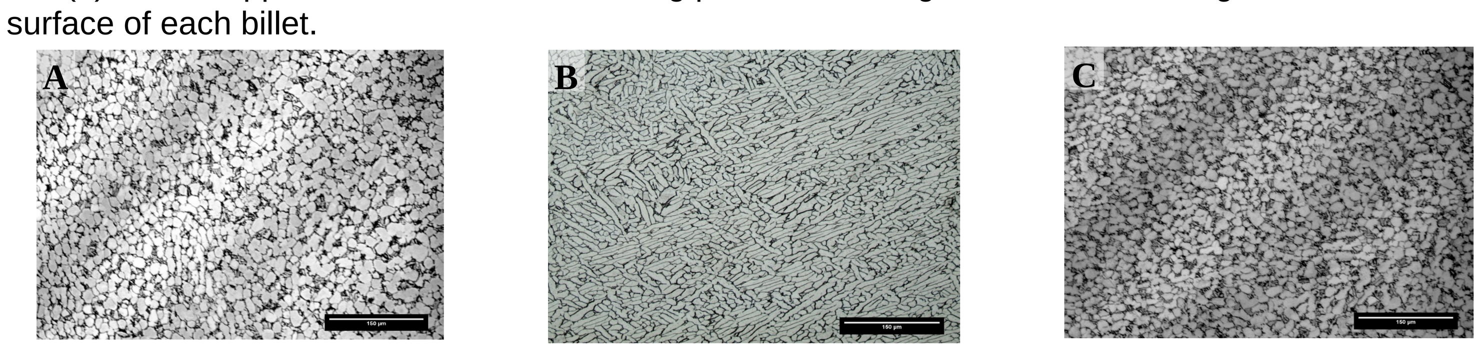
Alcoa's annealing process is seen to the right. The process begins with the beta anneal, heated above the beta transus temperature, to give only a beta phase microstructure. After an air quench, the recrystallization anneal begins. As it cools, the alpha plates nucleate to form the basket-weave structure. After the last reheat, the alpha grains fuse to become equiaxed.



Microstructure Results



3D microstructures for A Center (1), A 1 cm from Surface (2), B 1 cm from Surface (3), C Center, (4), and C 1 cm from Surface (5). Each supplier has a different billetizing process, leading to different resulting microstructures at the center and surface of each billet.



Microstructures taken with an optical microscope of the surface of each billet. Suppliers A and C display equiaxed alpha and beta grain morphologies, while supplier B shows a more elongated, plate-like alpha structure with intergranular beta phase. Grain size and aspect ratio are seen below for surface, 1 cm from surface and center.

Surface			
	A	B	C
Grains size (µm)	7.90	10.99	6.05
Aspect ratio	1.24:1	7.08:1	1.36:1

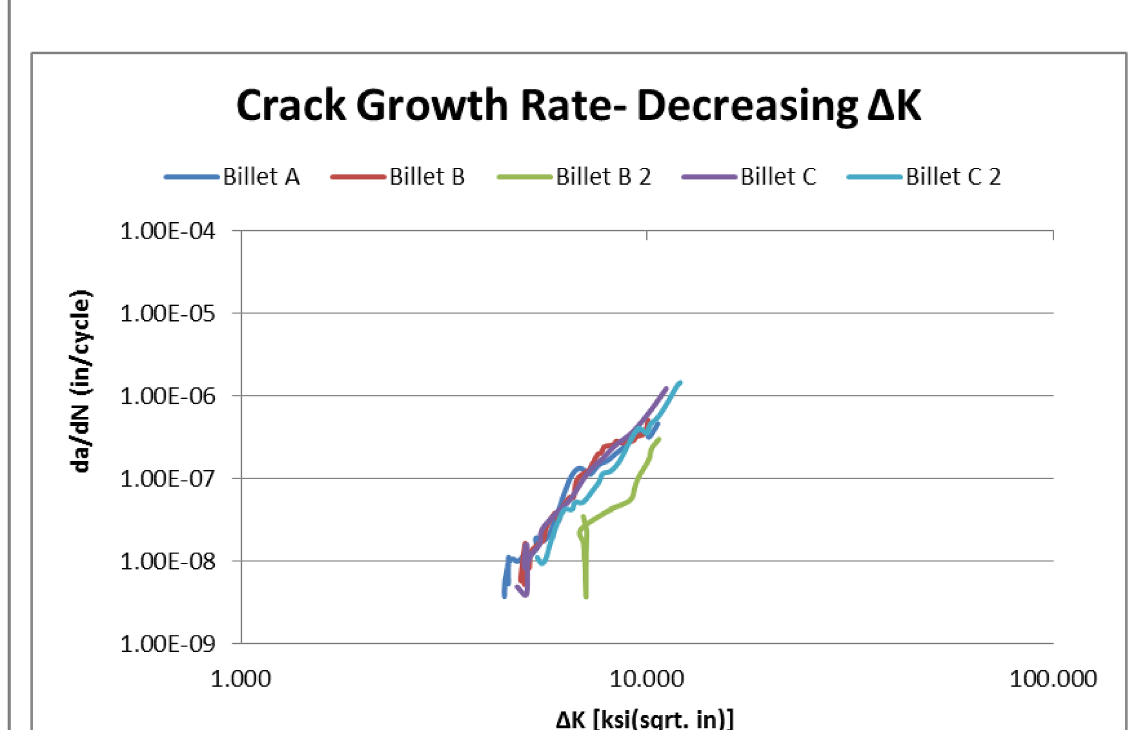
1 cm from Surface			
	A	B	C
Grains size (µm)	8.57	11.82	7.70
Aspect ratio	1.49:1	12.00:1	1.36:1

Center		
	A	C
Grains size (µm)	12.72	6.21
Aspect ratio	1.31:1	2.06:1

Mechanical Properties Results

Tensile Test					
	UTS (ksi)	0.2%YS (ksi)	Elong (%)	RA (%)	Modulus (Msi)
A	135.43	124.65	13.5	25.5	16.78
B	136.03	123.57	13.17	25.17	17.28
C	141.48	128.9	12.75	27.25	17.2

Fracture Toughness				
	YS (ksi)	KQ (sqrt.in)	Load PQ (lbs)	Strength Ratio
A	124.25	82.25	12532.5	1.061
B	124.4	92.2	13689.5	1.224
C	129.05	70.45	6651	1.016



Westmoreland Mechanical Testing and Research, Inc. performed the mechanical tests on each of the billets. The data produced did show a correlation between the mechanical properties and corresponding microstructure, especially seen in Billet B.

Model fatigue - crack propagation of large crack behavior in terms of crack growth rates, da/dN, as a function of applied stress-intensity range, Δk, at load ratio of 0.1, all at frequency of 20Hz.

Conclusion

Due to different processing methods of each supplier, the billets have varying microstructures. Billet B exhibits a plate-like alpha microstructure which, theoretically, should display lower mechanical properties compared to the equiaxed fine alpha grains in transformed beta matrix. Although there is no statistically strong correlation between these mechanical tests and microstructure, there is a decrease in the mechanical properties in Billet B. The results can be useful to Alcoa based on their specific customers' needs. An increase in sample size per test would further help determine this microstructure to property correlation.