MATERIALS™ EXPLORERS

THE MATERIALS THAT MOVE US: DATA COLLECTION AND GRAPHING

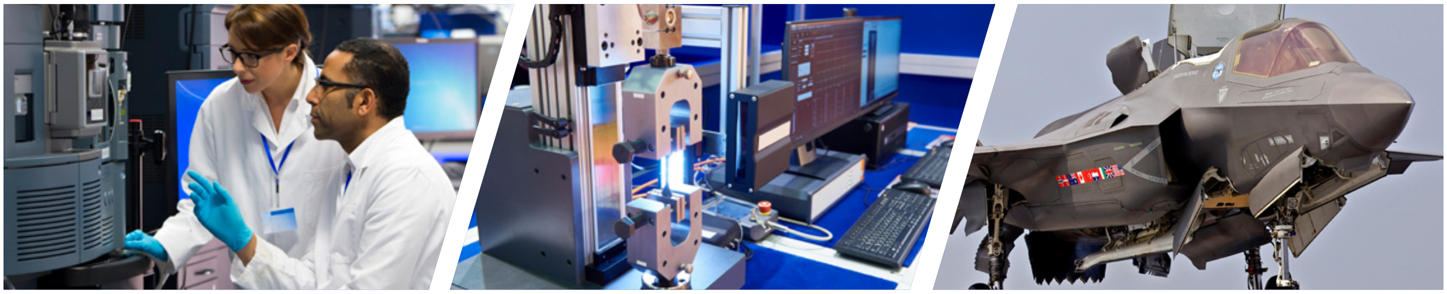
Learn about the scientific method by selecting the best materials for use in a commercial jet engine. Then, learn how rigorous testing helps ensure the safety and performance of parts used in military fighter jets.

In this module students will be able to:

- Identify the steps of the scientific method
- Analyze data and create a graph to reveal trends in the data
- Use data and graphs as evidence to draw conclusions about the relationship between two variables
- Compare composites to raw materials and explain the advantages of using composites in various industries

Class Activity

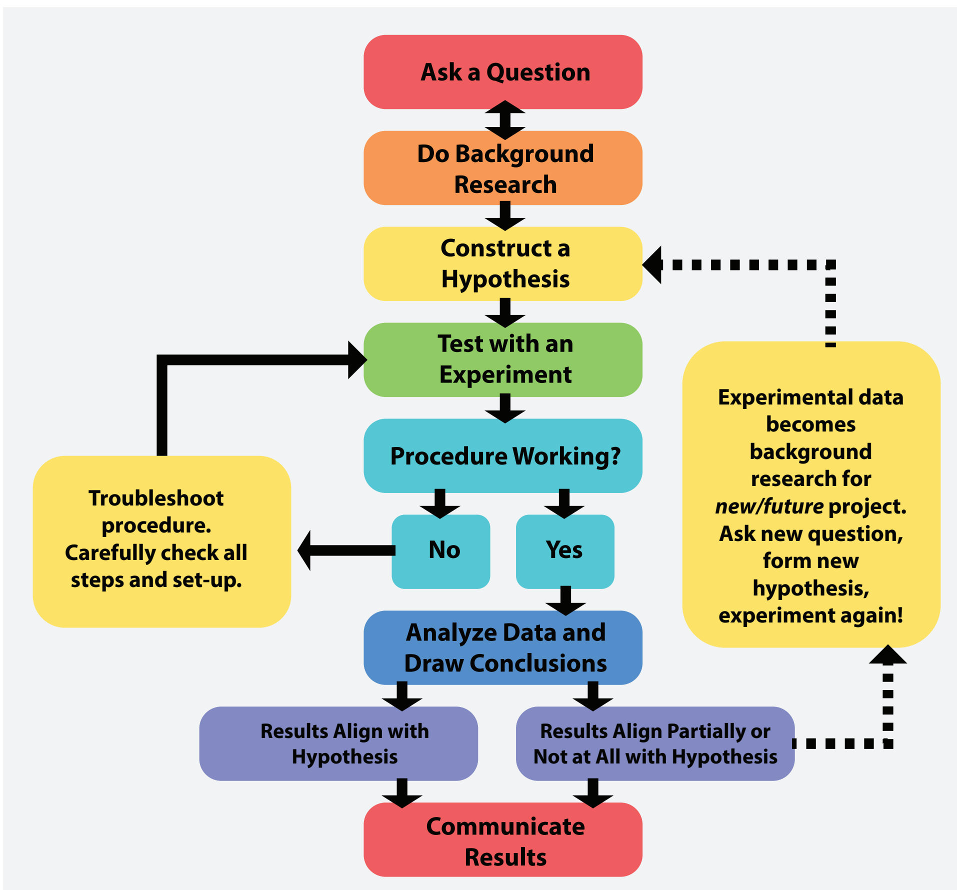
TESTING THE LIMITS



Background

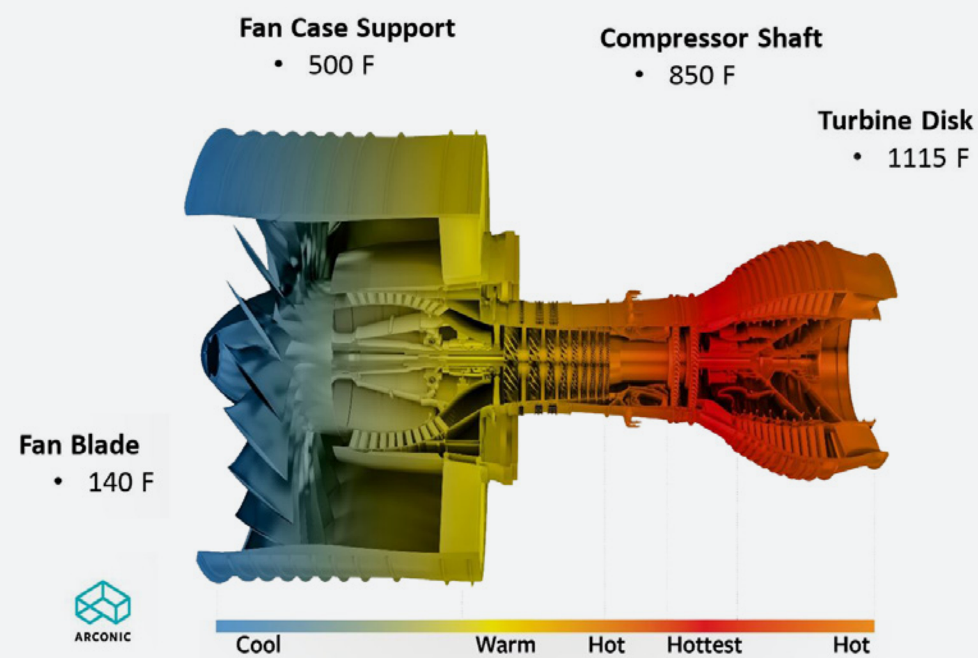
Have you ever noticed that scientists on television always seem to be taking measurements and gathering data? It's not just for dramatic effect.

Collecting data is an important part of the scientific method process. The scientific method is a logical or systematic approach to problem solving. The process is made up of a series of important steps: recording observations and developing questions; generating a hypothesis; experimenting; analyzing results; drawing conclusions; and reporting results. Access to accurate data enables researchers to test their hypotheses and draw scientifically sound conclusions.



The scientific method helps researches solve problems by guiding them through developing potential solutions and testing them. This chart shows the steps involved from the development of an idea to determining whether or not it will work.

Class Activity



This depiction of a jet engine shows the maximum temperature of various components when in use. (Photo courtesy of Arconic.)

If the steps of the scientific method sound too abstract, let's observe the method at work through a real-world example. Consider the image above which shows just how hot a jet engine can become when in use. When researchers are selecting the best material for a specific component, they can't just look up properties such as strength or elasticity because those qualities may be affected by other conditions such as the high temperatures the material must endure. Instead, they must employ the scientific method to ensure they are making the right choice.

Researchers must first *record observations* about the component and the conditions it will be exposed to. Then, they must develop questions that will guide their line of research such as, "what material can endure a great deal of stress above 500°F?" The team may then construct a *hypothesis* that specific materials might meet the identified need.

At this point, the team can begin testing their hypothesis through *experimentation* to see how the materials perform under different temperatures. After *analyzing* their results, and drawing a *conclusion* about the best material, the team can finally write a report which outlines their results and makes a suggestion for which material should be used.

How would you go about making your recommendations if you were a member of the research team? The following activity will show you.

Class Activity

Problem:

A new airplane manufacturer has hired your company to redesign their jet engine. You are the lead researcher tasked with determining the best materials for constructing various components.

Task:

Your team has conducted extensive testing on the properties of four alloys and presented their initial results to you. You must analyze their results to draw a conclusion about the best materials for building each component.

The tables below contain the results of your team's testing. They show how each alloy's **yield strength** and **Young's modulus** are affected by temperature.

Aluminum Alloy

Density = 0.100 lbs / in^3
Max Use Temperature = 300 F
Price = $1.62 / lb

Yield Stength		Modulus	
°F	ksi	°F	10^6 psi
-374	57	-262	9
-287	53	-198	9
-205	49	-120	9
-114	47	-27	9
-13	46	57	9
102	44	122	9
165	44	181	9
210	42	260	9
246	39	341	8
269	36	411	8
296	28	481	7
325	20	539	7
363	14	588	6
396	10	643	5
443	7		
506	6		
575	5		
651	5		

Titanium Alloy

Density = 0.160 lbs / in^3
Max Use Temperature = 850 F
Price = $9.33 / lb

Yield Stength		Modulus	
°F	ksi	°F	10^6 psi
-318	242	83	15
-272	222	297	15
-219	204	489	14
-168	190	703	13
-107	178	797	13
-33	167	869	13
58	155	933	12
136	145	996	11
207	135		
312	121		
424	107		
493	102		
565	99		
643	99		
746	96		
829	92		
898	85		
950	76		
992	64		

Nickel Alloy

Density = 0.315 lbs / in^3
Max Use Temperature = 1275 F
Price = $7.15 / lb

Yield Stength		Modulus	
°F	ksi	°F	10^6 psi
-325	167	-285	29
-245	161	-185	29
-165	156	-85	28
-85	151	15	28
-5	147	115	27
75	144	215	27
155	141	315	27
235	139	415	26
315	137	515	26
395	136	615	25
475	136	715	25
555	135	815	24
635	135	915	24
715	134	1015	23
795	134	1115	23
875	133	1215	22
955	132	1315	21
1035	131	1415	21
1115	128	1515	20
1195	121	1615	19
1275	114	1715	17
1355	97	1815	16
1435	73	1915	14
1515	57	2015	13

Iron Alloy (e.g. Steel)

Density = 0.285 lbs / in^3
Max Use Temperature = 900 F
Price = $0.49 / lb

Yield Stength		Modulus	
°F	ksi	°F	10^6 psi
-320	289	-113	26
-203	259	71	25
-75	246	363	24
72	236	567	24
236	223	662	23
375	214	795	22
509	203	915	21
648	193	980	20
778	183		
849	178		
904	169		
953	151		
983	130		

Table 1: Data showing how the properties yield strength and Young's Modulus are affected by temperature for four different alloys. This table is available for download as an Excel file on the Materials Explorers™ *website in the Extra Resources section of the "Materials That Move Us" web page. (Courtesy of Arconic.)*

Class Activity

Questions

1. Plot the following graphs in Excel, Google Sheets, or on graph paper. Make sure each graph TALKS (Title, Axes, Labels, Key, Spacing).
   a. Temperature vs yield strength. Include the results for all four alloys on the same graph.
   b. Temperature vs Young's modulus. Include the results for all four alloys on the same graph.
2. List the alloys from lowest to highest in terms of:
   i. Density
   ii. Maximum use temperature
   iii. Price
3. The compressor shaft operates at 850°F and needs a material with a very high yield strength at this temperature. Which alloy would be best for this part?
4. The fan blade operates at 140°F and needs a material with modulus (stiffness) between 10-20 x106 psi at this temperature. Which alloy would be best for this part?
5. The fan case support is currently made from aluminum but a next generation design will need to operate at temperatures as high as 350°F. A new fan case support design would need to be as lightweight as possible and be at least as stiff (modulus) and as strong (yield) as aluminum. What is the next preferred alternative to aluminum? Explain your answer.
6. You are designing a turbine disk operating at 1115°F. List the yield strength and Young's Modulus for the alloys that work at this temperature.
7. The use of raw or pure materials is limited in the transportation industry because alloys or composites (materials made from two different materials with significantly different chemical and physical properties) often have more desirable properties. Research a composite material such as carbon fiber, glass fiber, or fiberglass reinforced plastic utilized in any industry and explain the properties of the composite and why it is more desirable than the raw or pure materials.

Definitions

Alloy
A mixture of two or more metals, or a metal and other elements.

Yield Strength
The magnitude of stress at the point at which a material ceases to be elastic and becomes plastic.

Young's Modulus
Also known as the elastic modulus, Young's modulus is a measure of the elasticity of a material. The higher the Young's modulus of a material, the more the material will resist stretching. It can be calculated by dividing stress by strain.

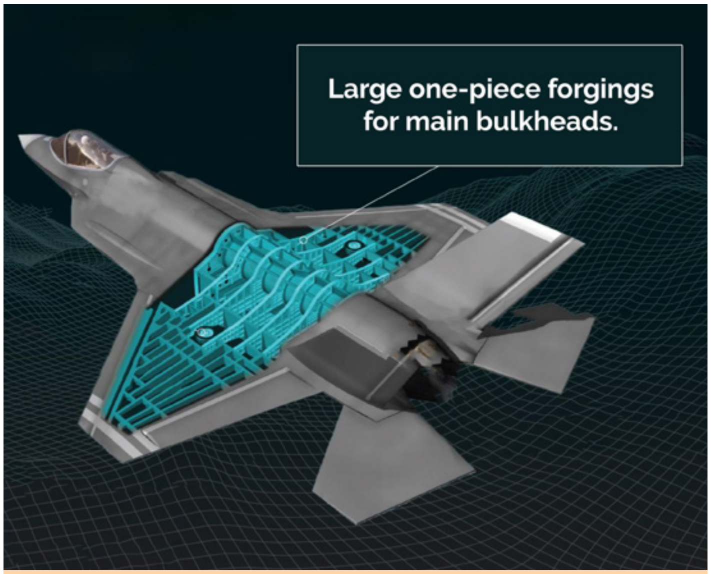
Extension Activity

SOARING TO NEW HEIGHTS

Numerous industries rely on materials science and engineering innovations to help make tougher, lighter, and more efficient products.

Take the example of the Lockheed Martin F-35 Lightning II, also known as the Joint Strike Fighter (JSF). This advanced defense aircraft is made up of single-piece forged aluminum or titanium bulkheads that form the "backbone" of the aircraft structure. This design helps save up to 400 pounds per jet—this translates into further costs savings and greater fuel efficiency.

Aircraft such as the F-35 Lightning II rely on extensive testing to make them tough enough to protect the men and women using them.



The F-35 Lightning II uses bulkheads that are forged in a single piece. These bulkheads make up the "backbone" of the aircraft. (Image courtesy of Arconic.)

As you can imagine, a military aircraft such as the JSF needs to be able to tolerate some pretty extreme conditions and because the bulkheads are centrally located within the aircraft, they need to remain stable and intact. It must endure air-to-air or air-to-ground combat, be stealthy and agile, and reach speeds faster than the speed of sound!

The people operating or relying on this military aircraft need to be confident that it can handle all of these conditions. This is why researchers extensively test the materials used on the JSF to see how they will perform in real world conditions.

An example of this is seen in the rigorous **fracture toughness** testing that the JSF's bulkheads must undergo. Fracture toughness testing helps scientists quantify how well a material can resist fracturing once a sharp crack has been established. In other words, fracture toughness testing helps researchers know how quickly a crack will spread once it has formed. The pictures below will give you a better idea of how the test works.

Extension Activity

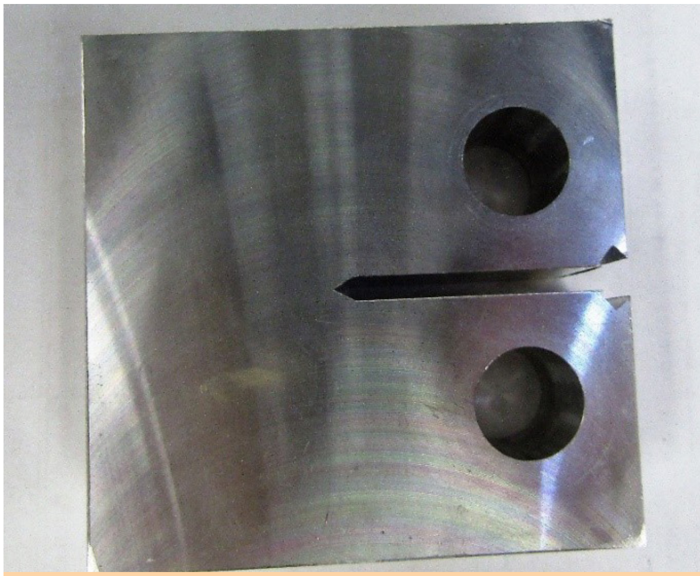


Figure 1: Testing starts by selecting the right specimen. Notice the notch in the specimen; as a load is repeatedly applied to the specimen, a small crack will begin to grow from the notched area. (Photo courtesy of Arconic.)

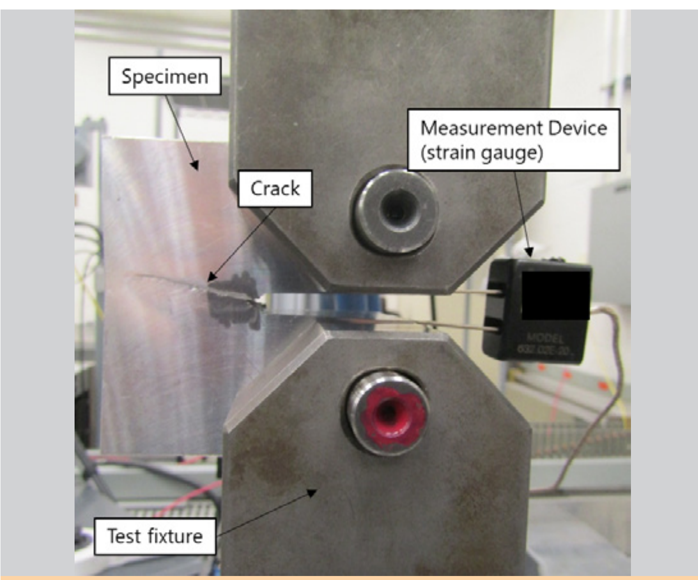


Figure 2: After a crack forms in the specimen, a measurement device is attached to the notch to measure how much the distance between the top and bottom of the notch grows as an increasing load is applied. (Photo courtesy of Arconic.)

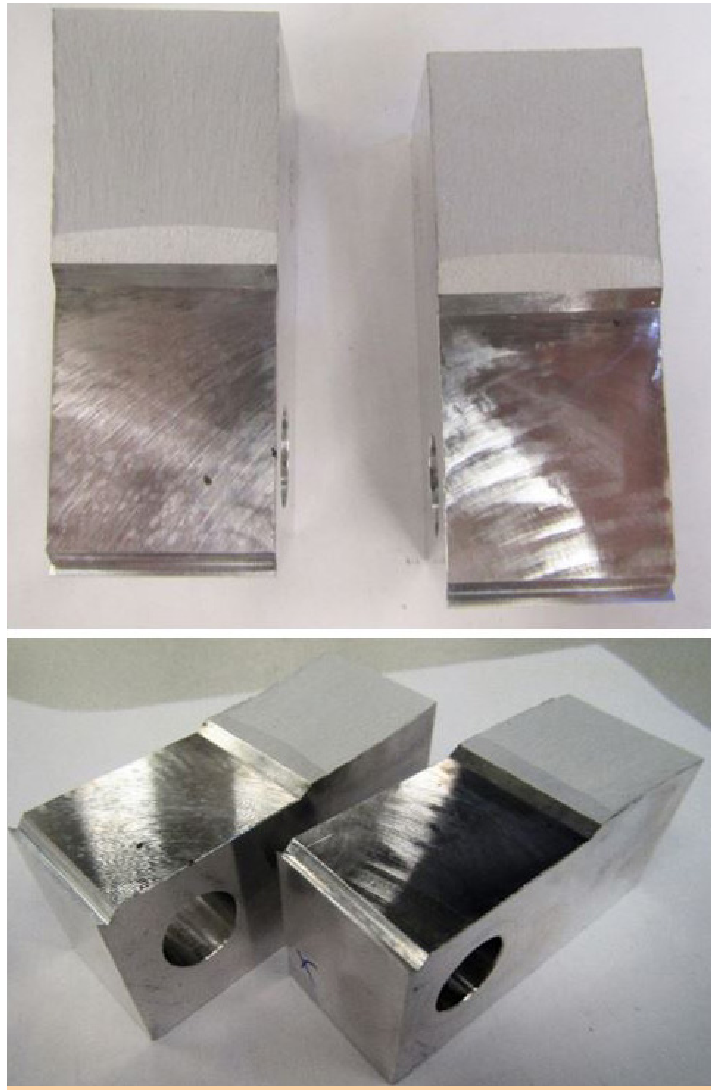
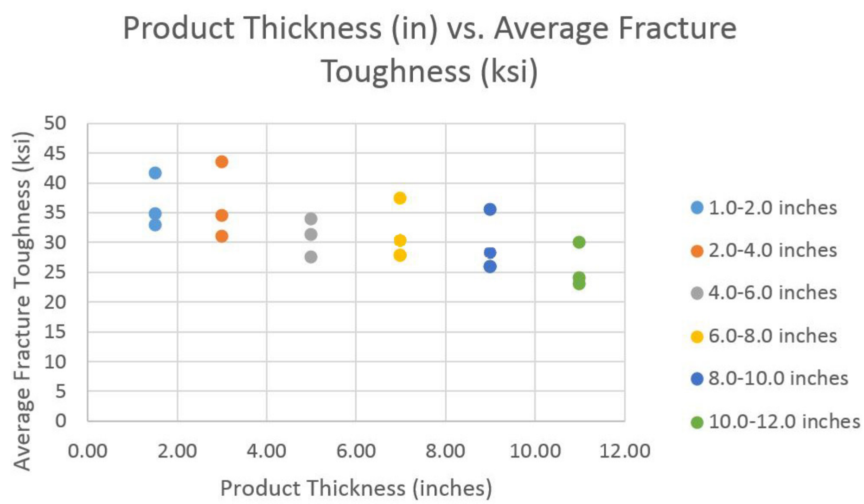


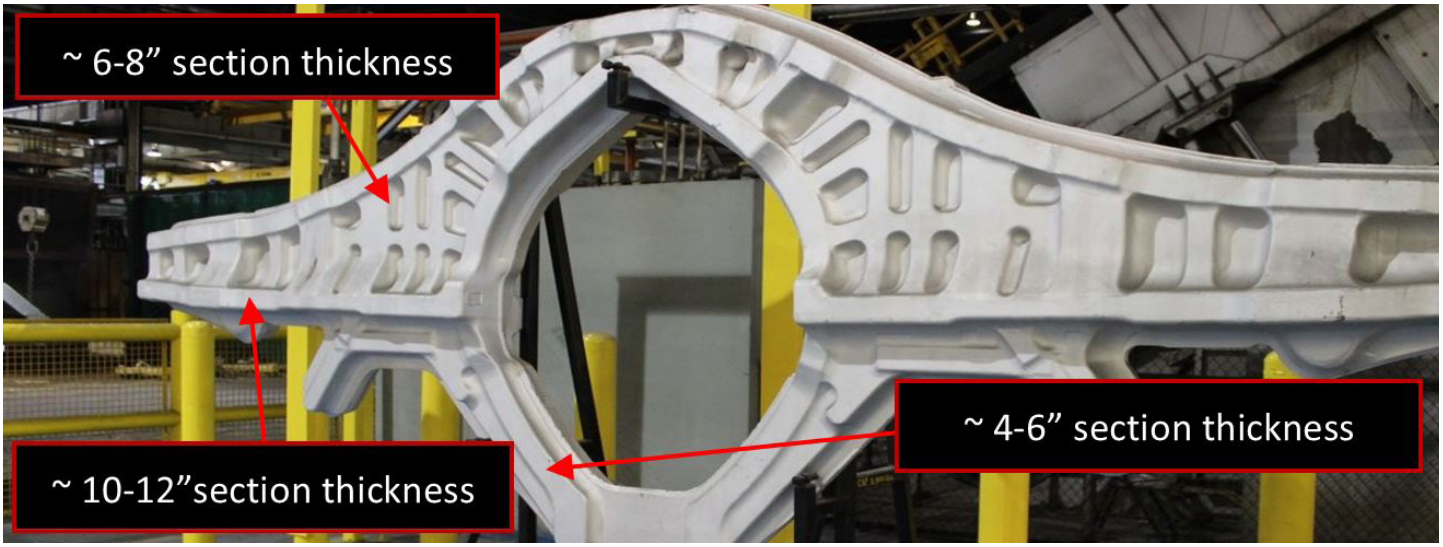
Figure 3: At the end of the test, the specimen is broken open to look at the microstructure of the crack. Lastly the fracture toughness values are calculated, and the results are validated. (Photos courtesy of Arconic.)

Extension Activity

1. The graph to the right shows the fracture toughness for the various section thicknesses required to compose the one-piece forgings for the main bulkheads in an F-35 Lightning II. Which section thickness actually had the highest fracture toughness?



2. The figure below shows the material thickness required to compose the one-piece forgings for the main bulkheads in a F-35 Lightning II. Which thickness would you expect to have the highest fracture toughness? Why?



3. Thinner materials are more susceptible to ductile fractures as opposed to brittle fractures. Research both ductile and brittle fractures and distinguish between each.

Definition

Fracture Toughness
The ability of a material to resist fracture.

MATERIALS™ EXPLORERS

The "Materials That Move Us" curriculum was developed through generous support from the Arconic Foundation.

ARCONIC FOUNDATION

Materials Explorers™ is a STEM educational outreach initiative of The Minerals, Metals & Materials Society (TMS). TMS is non-profit, international professional society with a mission to promote the global science and engineering professions concerned with minerals, metals, and materials.

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