Friction Stir Processing of D2 Tool Steel for Enhanced Blade Performance

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Key Points

- Background
  - FSP Technology
  - FSP for Microstructural modification
  - FSP for Property Modification
  - Knife Sharpness Testing
  - D2 Steel
- Experimental Methods
- Microstructure Results
- Knife Performance Results
- Qualitative Performance Tests

Friction Stir Processing

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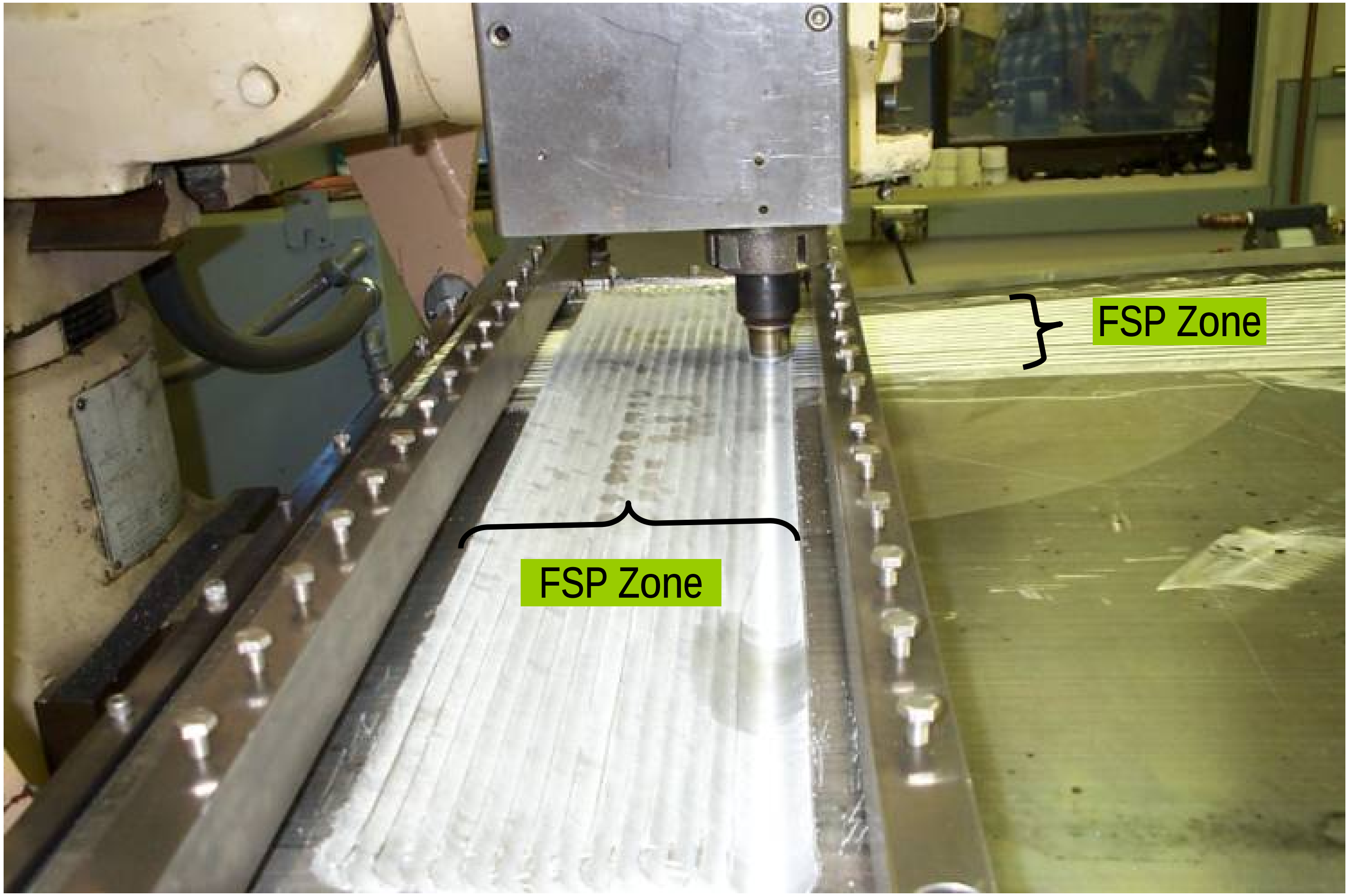
FSP for Microstructural/ Property Modification

- Thick-section superplasticity
- NiAl Bronze propellers
- Bending of high-strength Al alloys

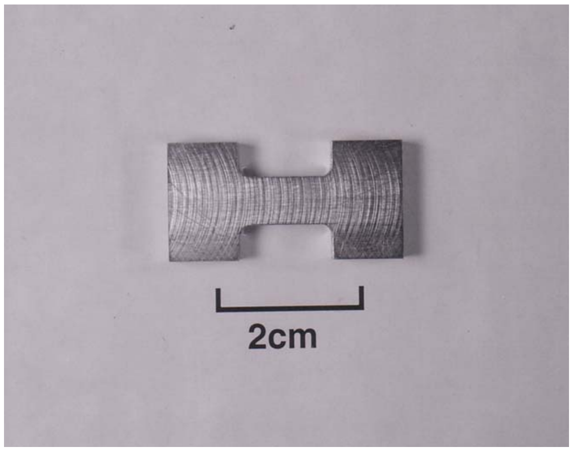
Friction Stir Processing of 0.2" thick 7475 Al Sheet



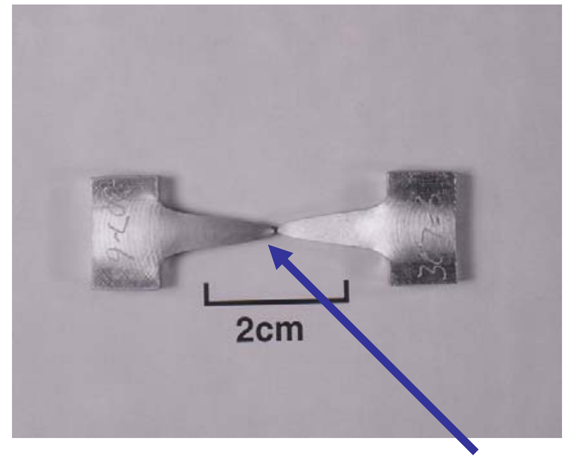
Selective FSP for local superplastic forming

Thick Section Superplasticity

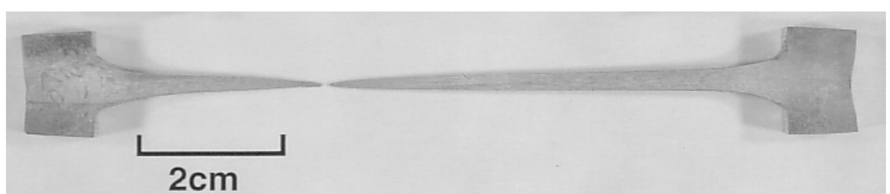
Conventional versus superplastic metal flow in 5mm thick 7050 aluminum



Starting Sample



Conventional Flow: severe necking



Fine grain created via FSP

Superplastic Flow:

- Uniform strain >600%
- Fracture strain >800%

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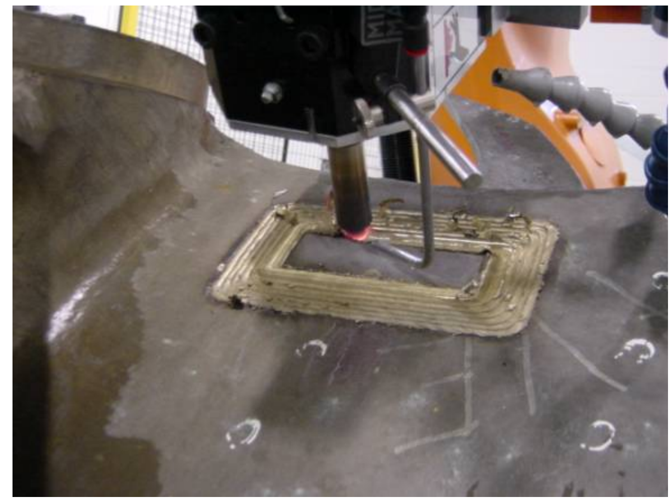
Casting Modification

- FSP of NiAl Bronze Castings for U.S. Navy



Raw casting contains:
- very large grain size, and
- lots of porosity

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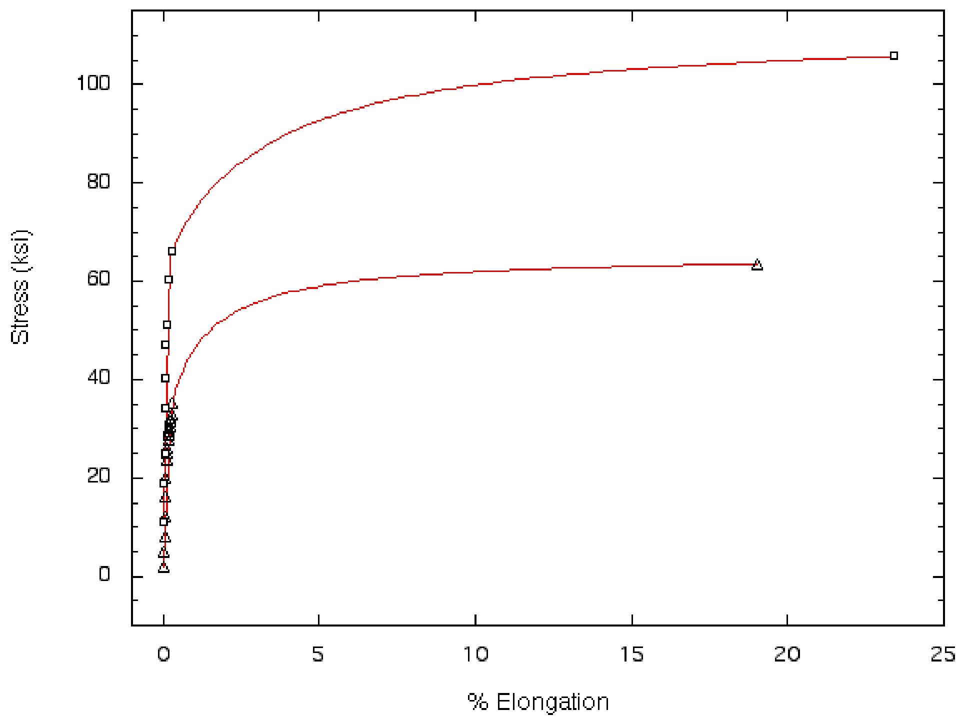
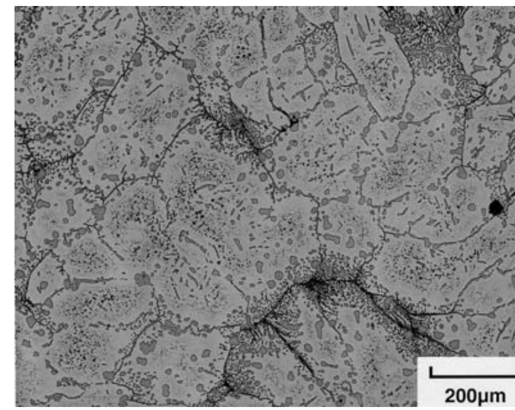
DiamondBlade Friction Forged™ Technology

Casting Modification

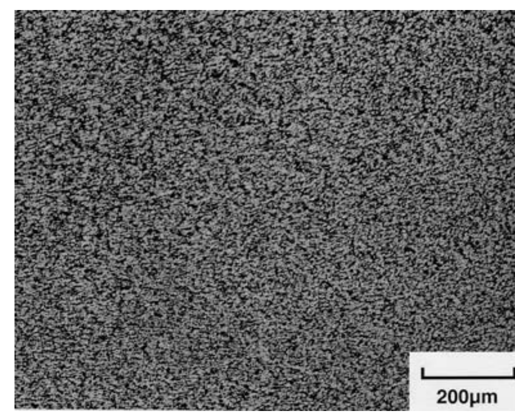
- FSP NiAl Bronze Casting

Yield strength	Tensile strength
63ksi vs. 31ksi	108ksi vs. 65ksi





As-Cast Microstructure

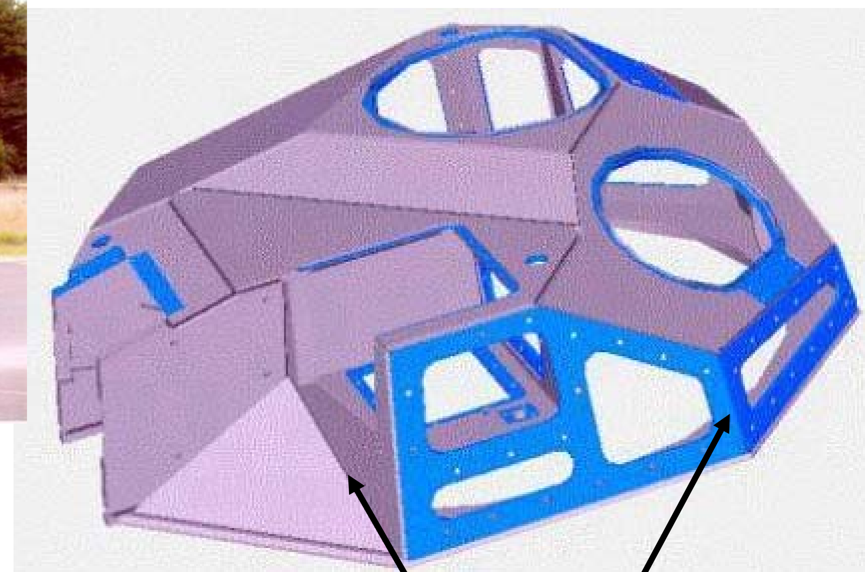


FSP Microstructure

EFV application for FSP enhanced thick section bending

Expeditionary
Fighting
Vehicle

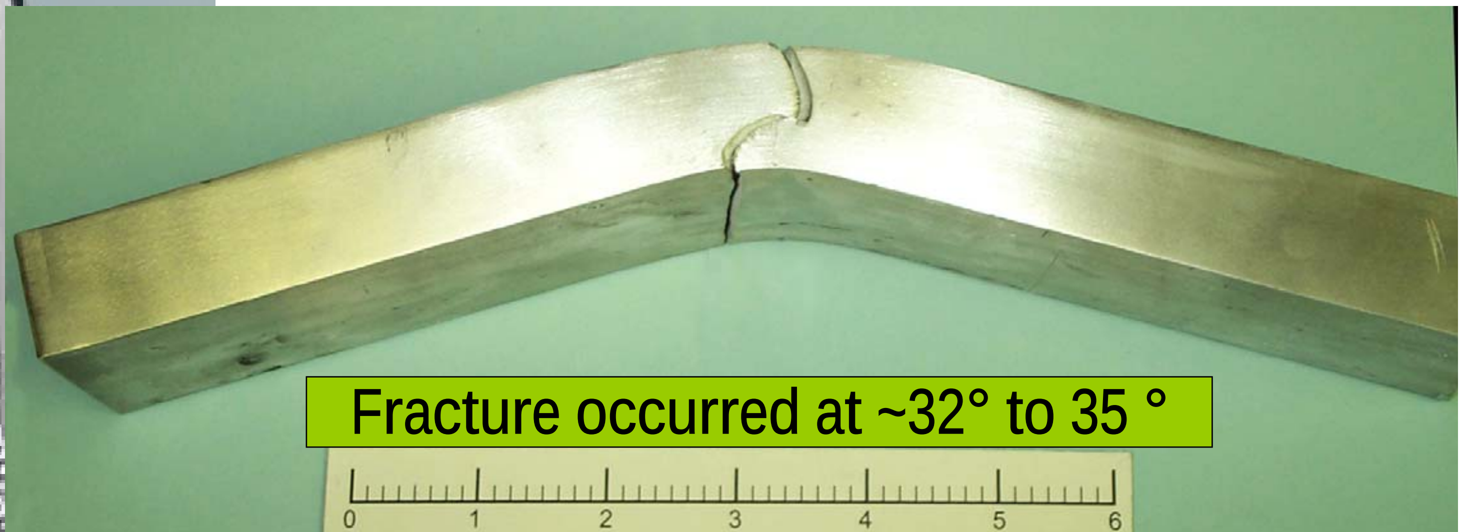
EFV Turret



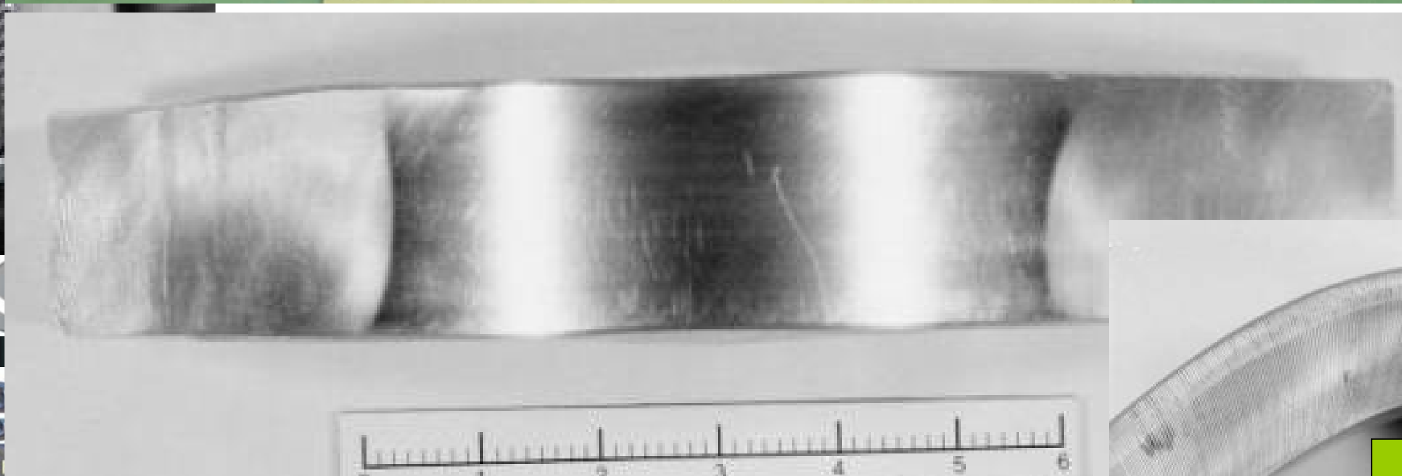
Welded thick Al plate construction
potentially replaced via FSP bending

Benefits: Improved properties
and potentially lower cost

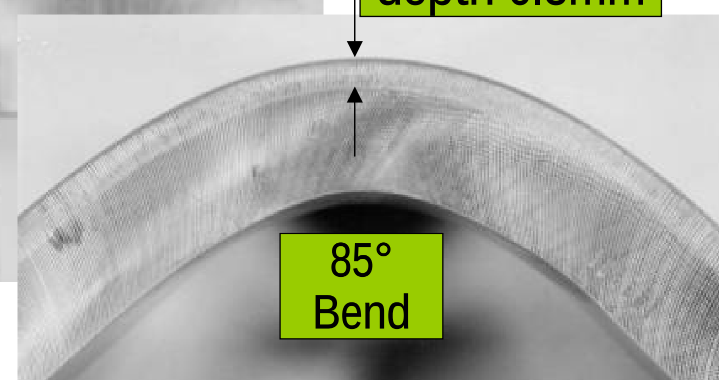
Bending of As-Cast and FSP 2519 Aluminum



Bending performed at room temperature (20ºC)

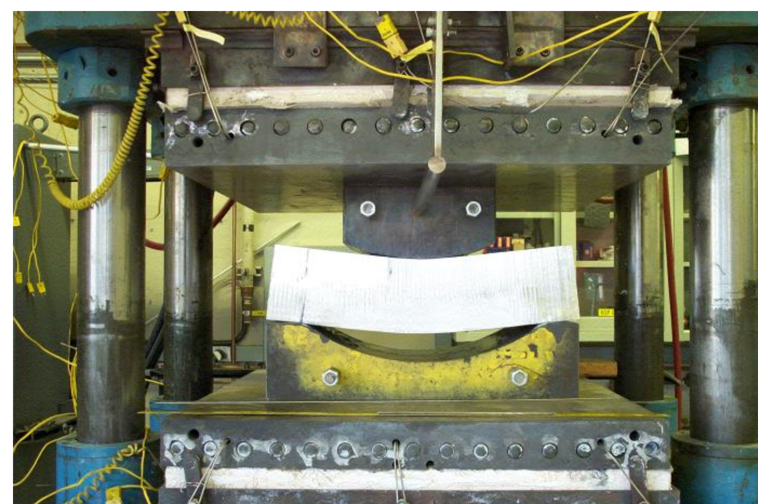


Smooth surface with no indication of impending fracture



Thick section Bending

- **152 mm FSP 6061 bent at room temperature**
  - **FSP bends 30º without failure**
  - **Parent fails at 7º**



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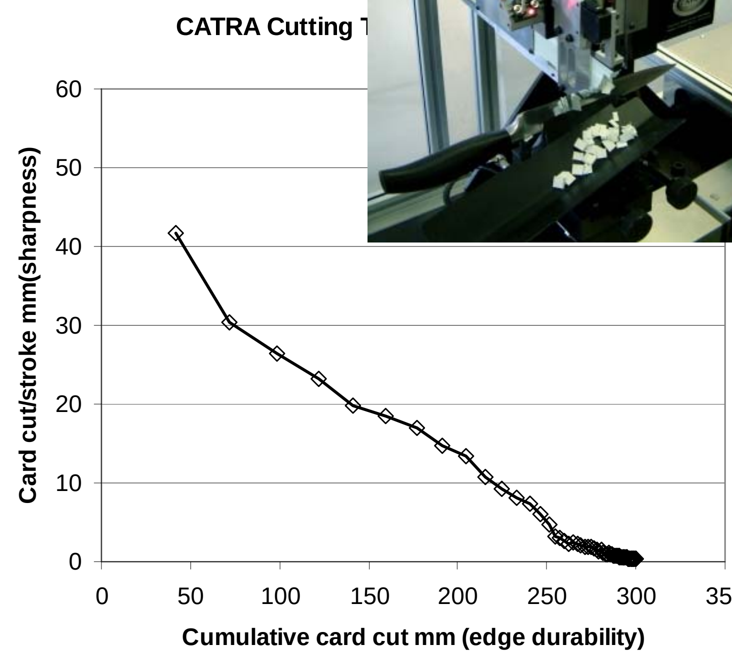
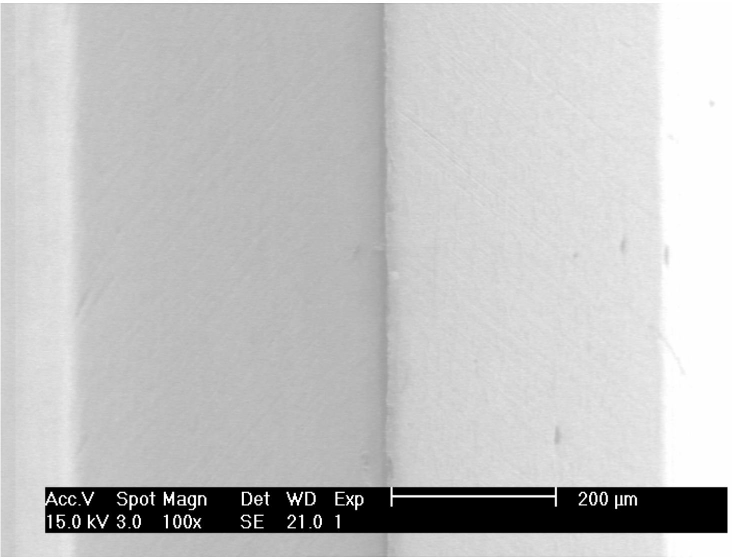
DiamondBlade Friction Forged Technology

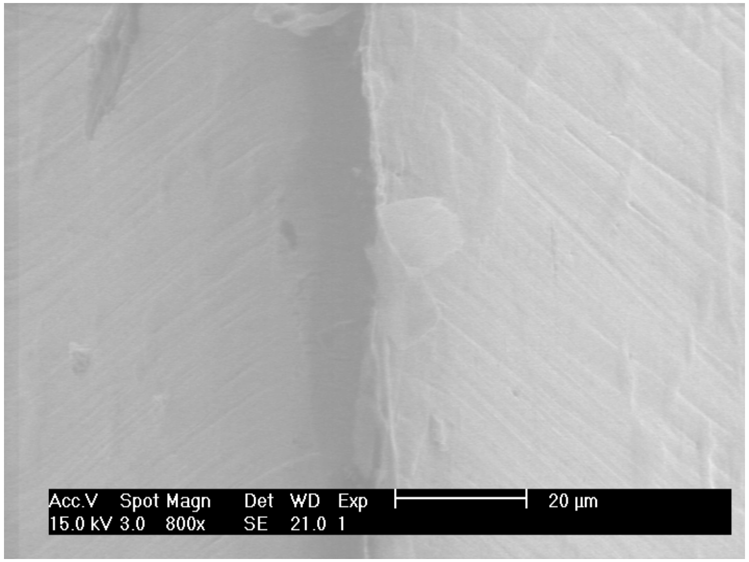
Sharpness Testing: CATRA Edge Retention Tester

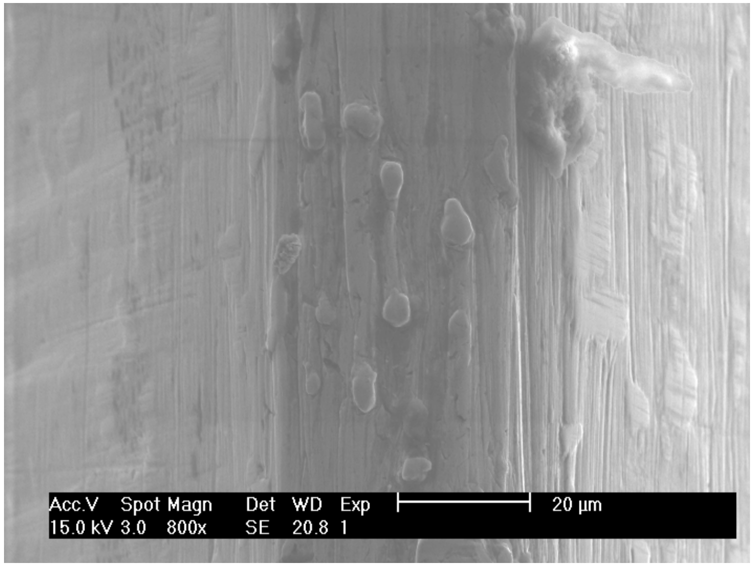
- Standard medium: card stock impregnated with silica
- Constant cutting parameters
  - Force perpendicular to edge
  - Cutting speed and stroke length
- Measure thickness of media cut with each stroke



Sharp and Dull Edges

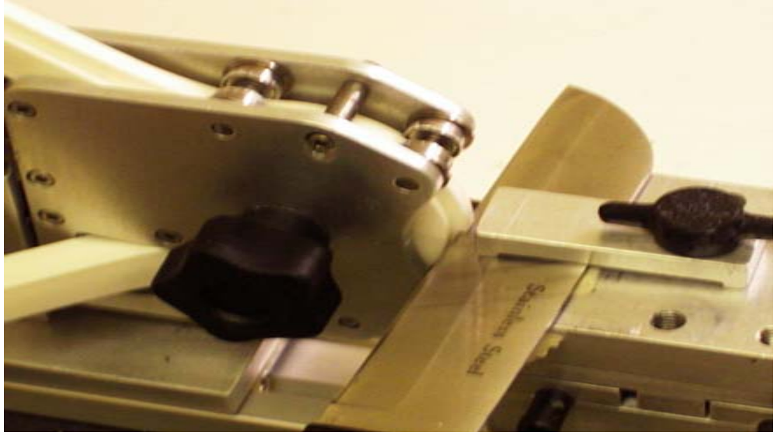


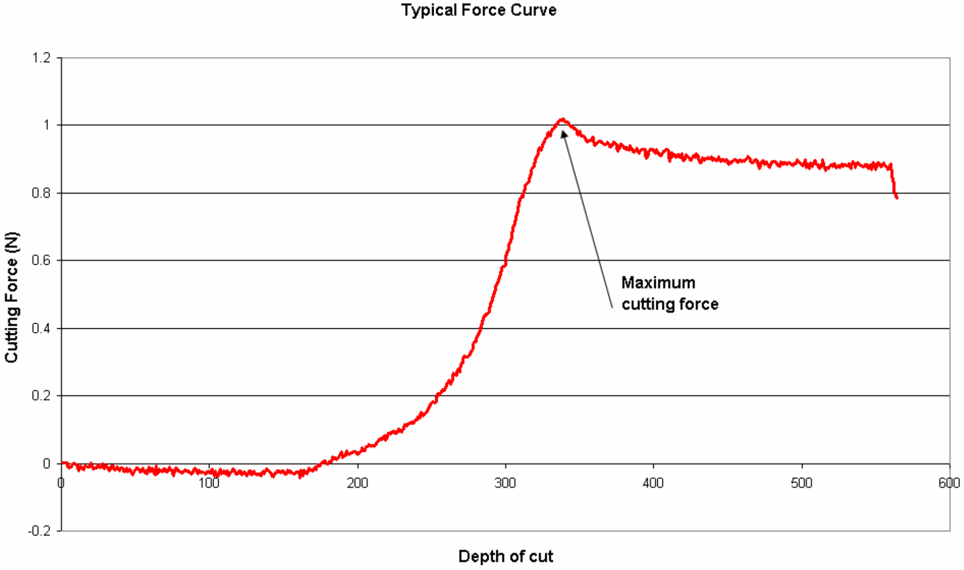




Sharpness Testing: CATRA Razor Edge Sharpness Tester

- Controlled medium: extruded silicone similar to weather stripping
- Press edge into medium with no motion parallel to edge
- Measure peak force; low force implies high sharpness





D2 Steel

- Air-hardenhable, high Cr cold-work tool steel
- Cr and V for high hardenability
- Significant wear resistance due to high carbide content
- Not stainless due to Cr tied up in carbides

C	Cr	Mn	Si	Ni	Mo	V
1.4-1.6	11.0-13.0	0.6 max	0.6 max	0.3 max	0.7-1.2	1.1 max

Experimental Methods

- Process straight D2 blades, with DOE controlling parameters
- Transverse specimens for optical microscopy and microhardness testing
- Blade edge cut with waterjet to avoid HAZ
- CNC grinding of edge; final sharpening using fixture to control geometry
- Use modified CATRA test with manila rope instead of CATRA media to wear blade
- CATRA REST used to measure sharpness

Tool Geometry

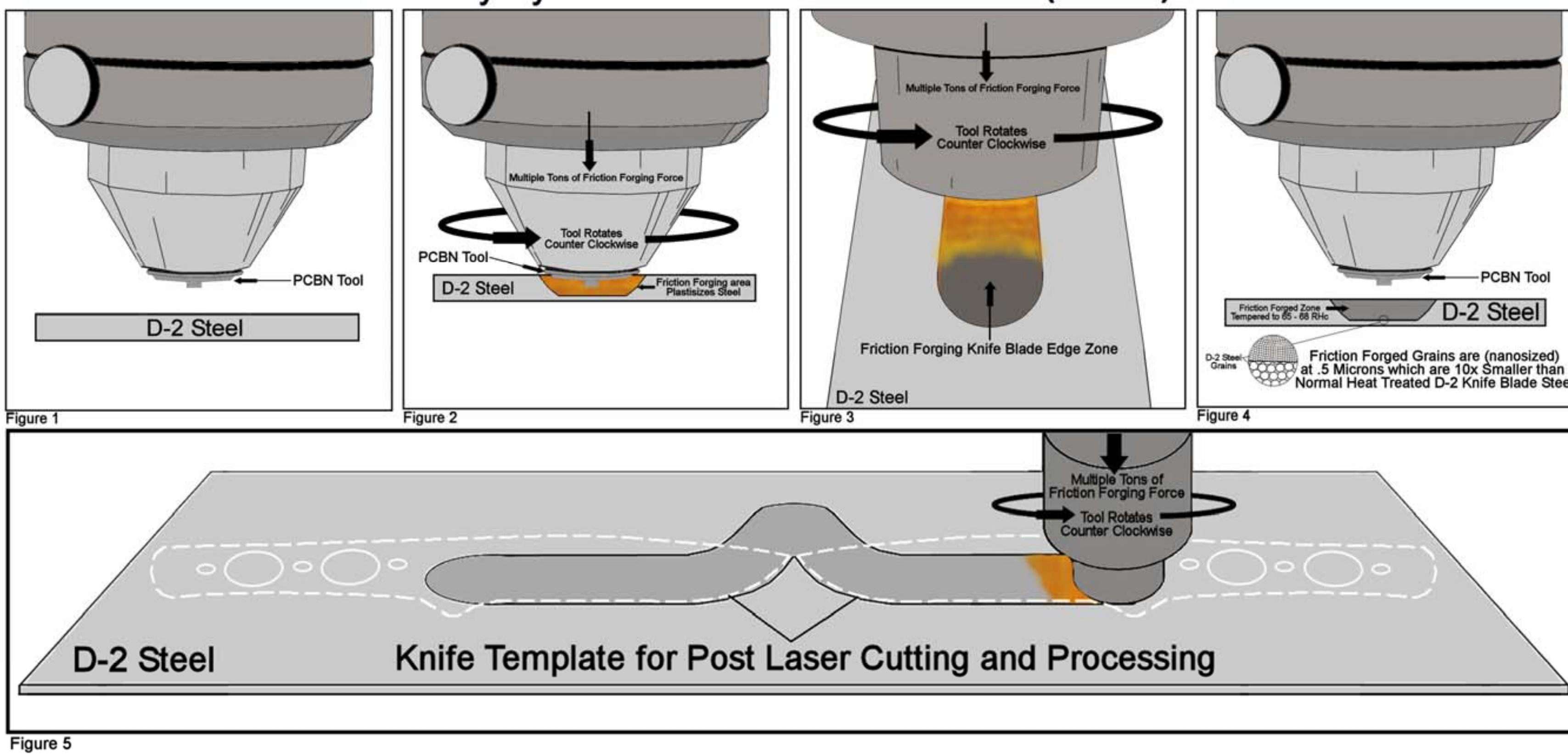
- PCBN tool, CS4 Shoulder geometry
  - Shoulder convex radius 3.5 in. (90 mm)
- 0.140 in. (3.5 mm) thick sheet
- 0.090 in. (2.2 mm) long pin
  - Partial penetration processing
- 15 degree pin half angle
- Step spiral or three flats on pin, depending on DOE

DOE Parameters

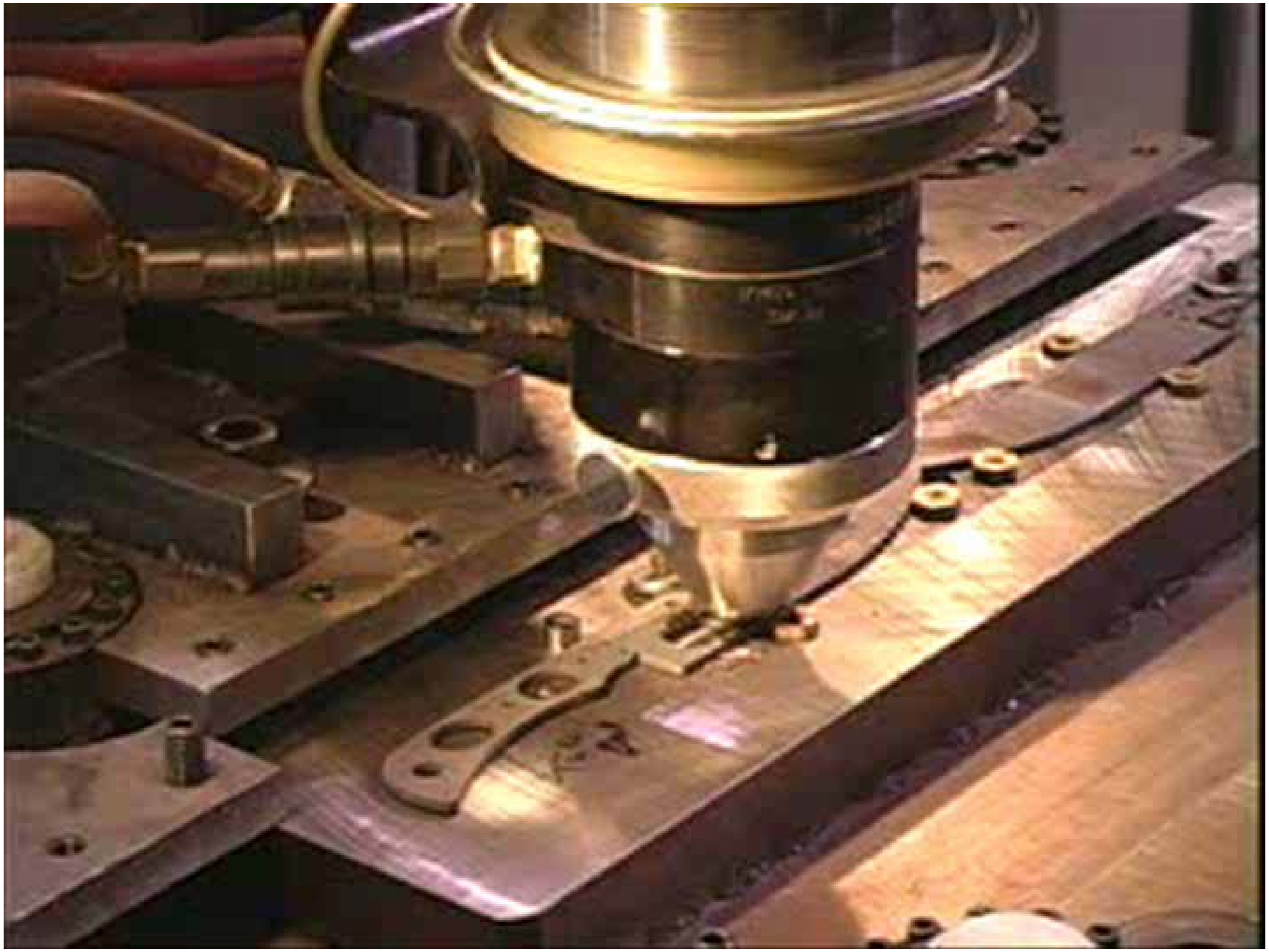
Weld Side Next to Blade Edge	Spindle Speed, RPM	Feed, IPM	Hardness	Pin	Blade IDs
Retreating	300	3	40	Stepped Spiral	2-1, 2-2
Retreating	450	3	30	Stepped Spiral	4-1, 4-2
Advancing	300	5	30	Stepped Spiral	5-1, 5-2
Advancing	450	5	40	Stepped Spiral	7-1, 7-2
Advancing	300	3	30	Tri-flat	1-1, 1-2
Advancing	450	3	40	Tri-flat	3-1, 3-2
Retreating	300	5	40	Tri-flat	6-1, 6-2
Retreating	450	5	30	Tri-flat	8-1, 8-2

FF of D2 Knife Blanks

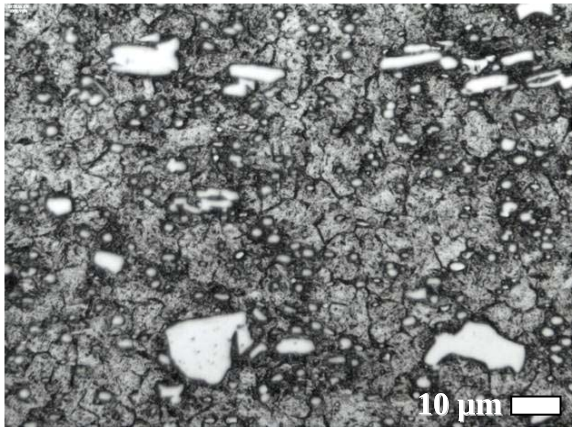
Polycrystalline Cubic Boron Nitride **(PCBN)**



Processing



Metallography

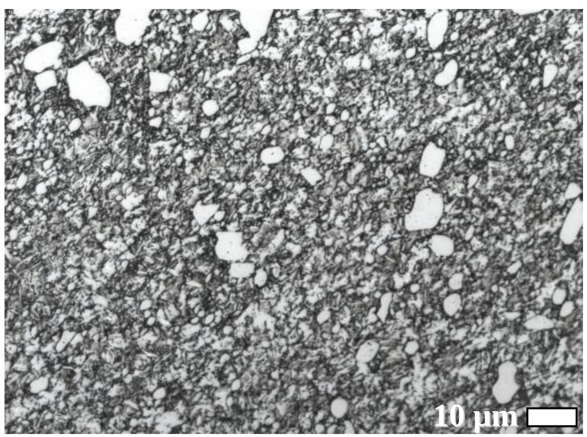


Base Metal

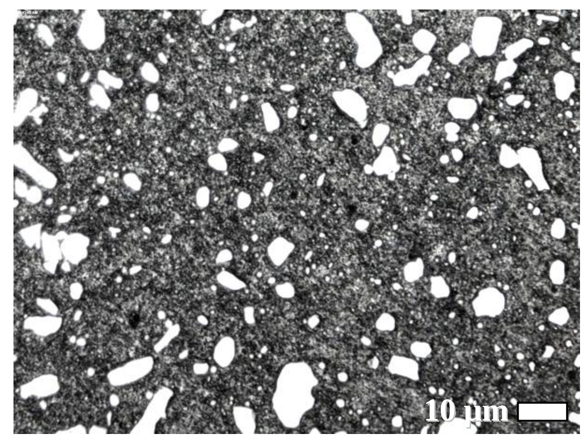
Large carbides reduced in size

Small carbides smaller and more widespread

Grain size reduced by order of magnitude

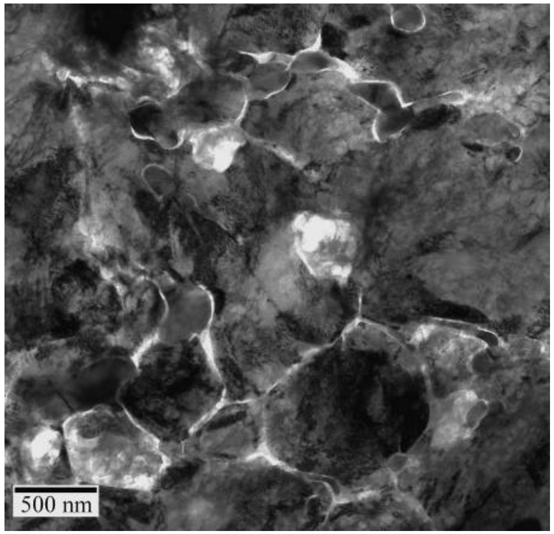


600 RPM, 4 IPM



250 RPM, 4 IPM

Metallography (cont.)



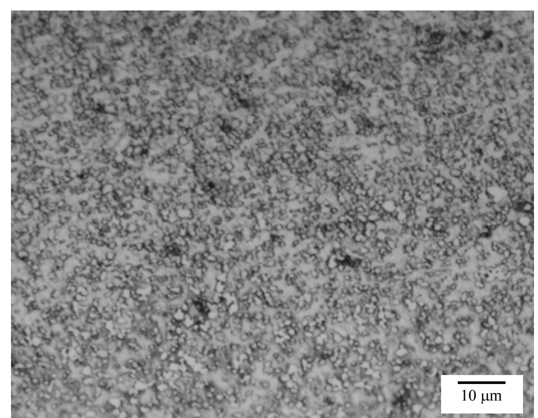
FSP D2 – 250 RPM, 4 IPM

Sub-micron grain size; 200-500 nm

S30V Powder Metallurgy Alloy

Fine grains of 2-5 µm

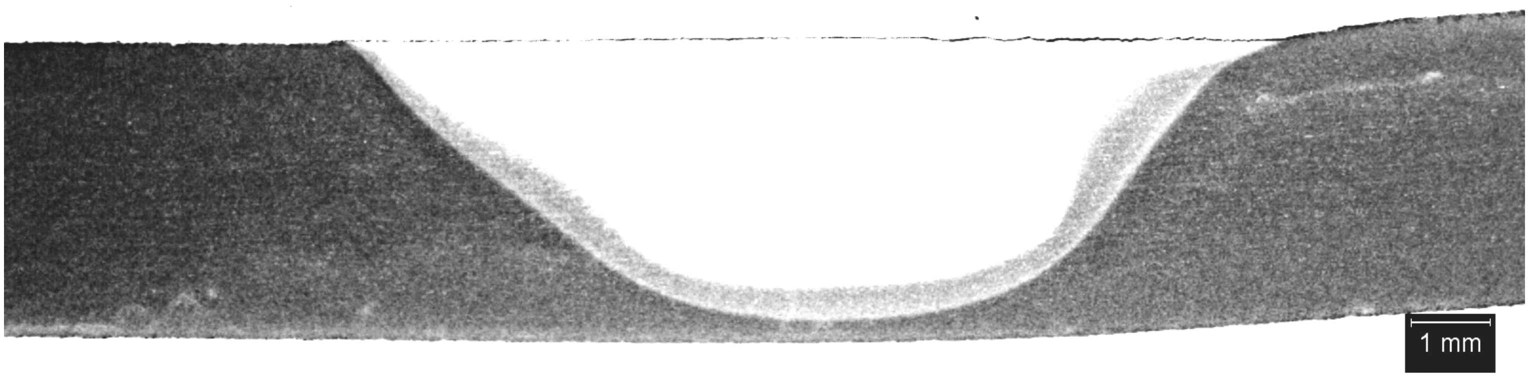
10x the size of FSP



ASTM Grain Size

ASTM Micro-Grain Size Number G	"Diameter" of Average Grain Section[A]	
	Nominal d_n, mm	Feret's d_f, mm
00[E]	0.51	0.570
0	0.36	0.403
0.5	0.30	0.339
1.0	0.25	0.285
1.5	0.21	0.240
(1.7)[F]	0.200	0.226
2.0	0.18	0.202
2.5	0.15	0.170
	µm	µm
8.0	22	25
(8.4)[F]	20	23
8.5	19	21
9.0	16	18
(9.2)[F]	15	17
9.5	13	15
10.0	11	13
(10.3)[F]	10	11.3
10.5	9.4	10.6
(10.7)[F]	9.0	10.2
11.0	8	8.9
(11.4)[F]	7.0	7.9
11.5	6.7	7.5
(11.8)[F]	6.0	6.8
12.0	5.6	6.3
(12.3)[F]	5.0	5.6
12.5	4.7	5.3
13.0	4.0	4.5
13.5	3.3	3.7
(13.8)[F]	3.0	3.4
14.0	2.8	3.2
(14.3)[F]	2.5	2.8

Increased Cr in Processed Zone



Macrograph shows no attack in processed zone with Nital

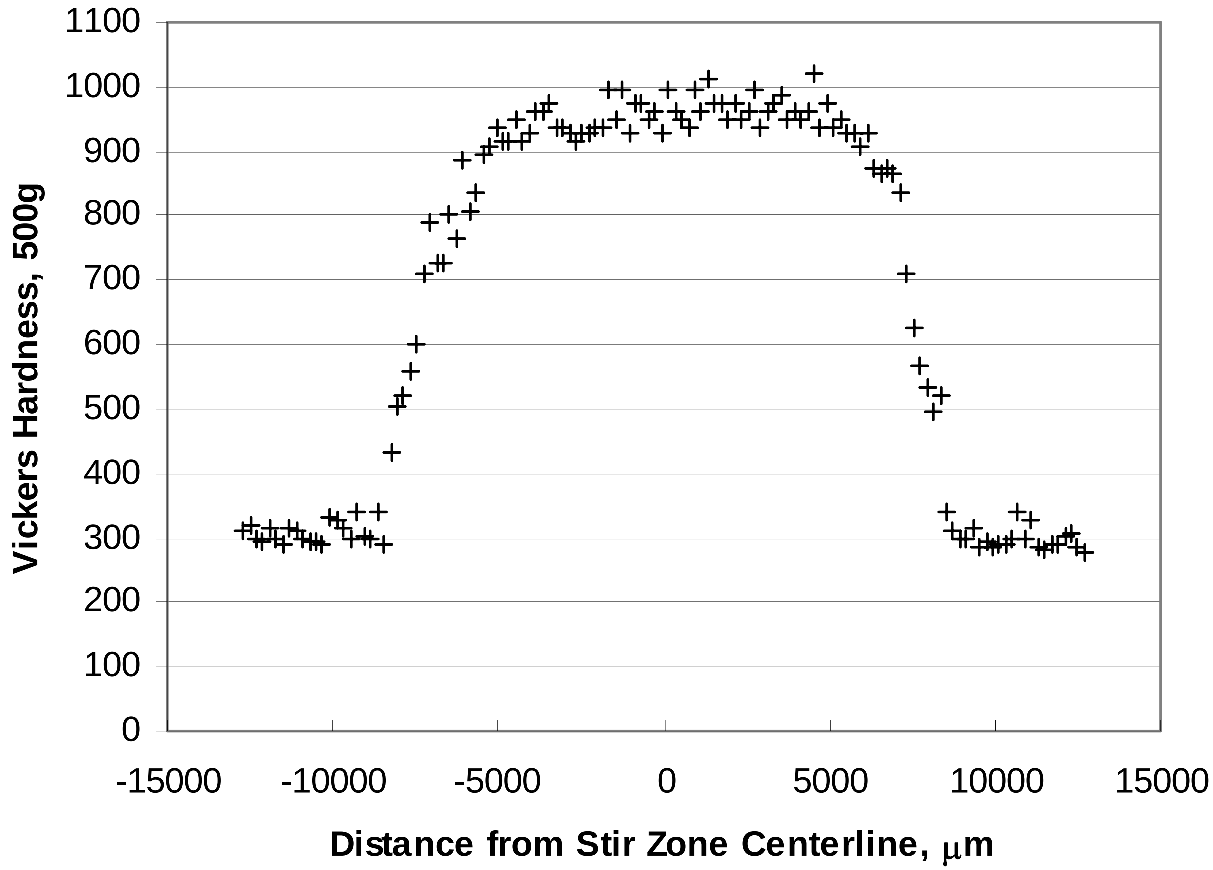
Zone is stainless

Higher Cr in solution increases strain energy and hardness

Stainless prevents corrosion at the cutting edge to reduce sharpness; minimizes chemical wear

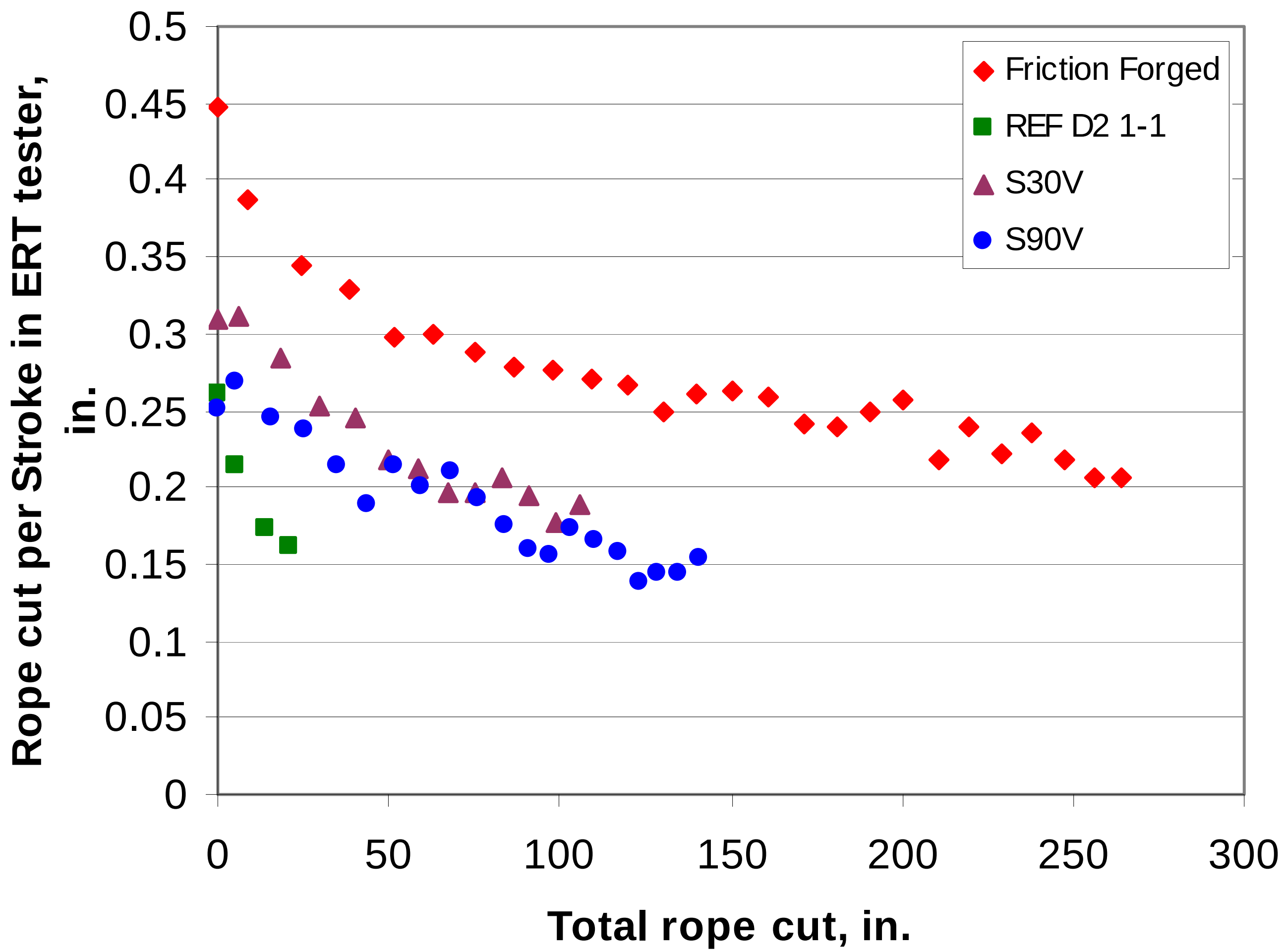
Cr comes from dissolved and reduced size carbides

Microhardness of Processed Zone



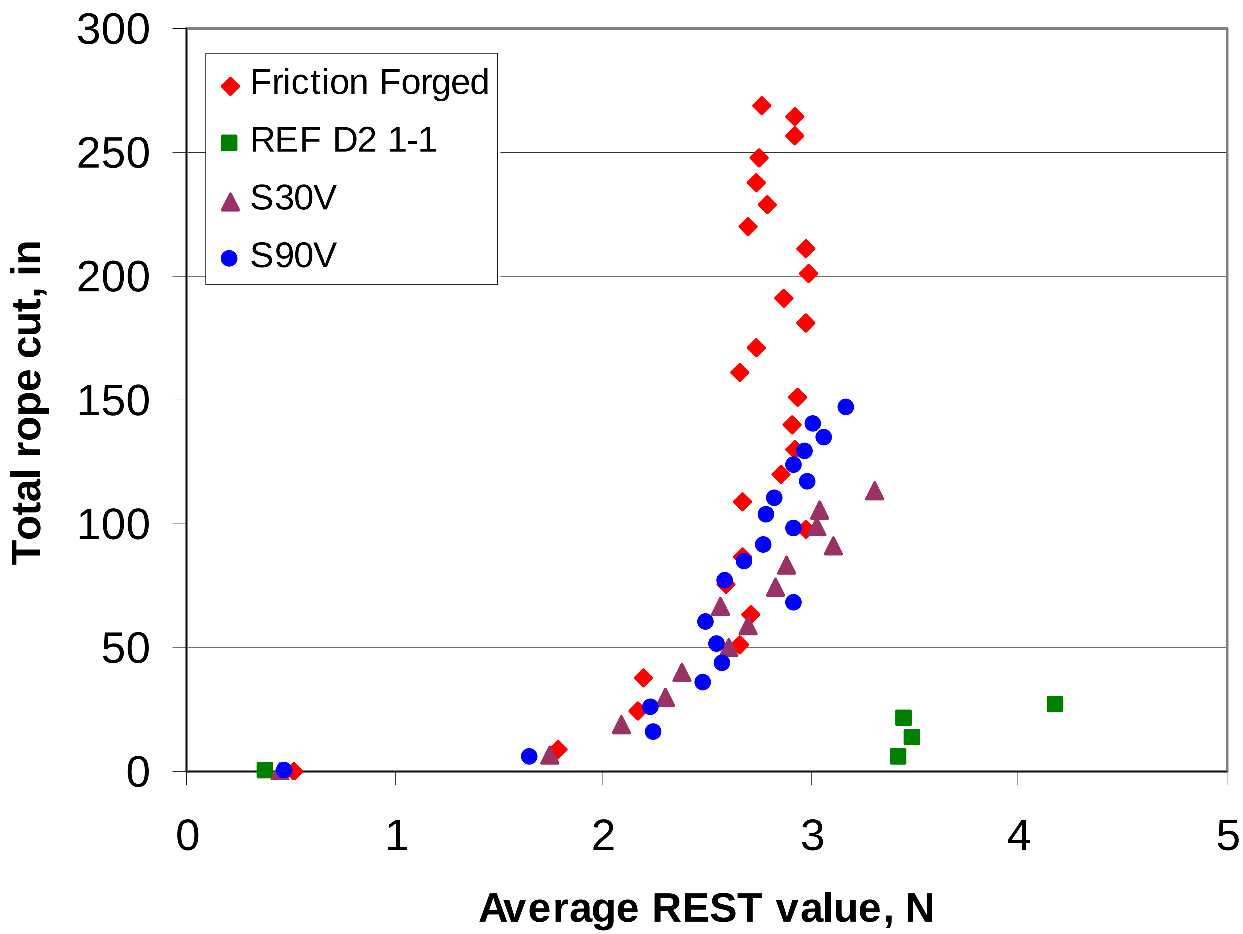
Stir zone hardness of up to 1000 HV (equivalent to 67 RC)

Knife Performance – Modified ERT



Uses manila rope, instead of silica-impregnated paper

Performance – Rope Cut to Dull



Summary

- FSP of D2 steel leads to increased performance of blade edges
- FSP D2 is stainless due to increased Cr in matrix
- Prior austenite grain size in FSP D2 is between 200 and 500 nm
- Hardnesses up to 1000 HV are found in FSP zone
- Blade has outstanding sharpness, toughness, and durability

Questions?

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