Sub-Liquidus Casting: Process Concept & Product Properties

PRESENTATION OUTLINE

- SSM Process Advantages & Cost-Effectiveness
- The SLC Slurry Process
- What Makes SLC Work?
- Properties and Characteristics
- Summary

SSM: ADVANTAGES

- **SSM Components are very much akin to Conventional HPDC:**
  - **Near Net Shape**
  - **Thin (but also Thick) Cast Wall Sections**
  - **Great Detail and Complexity, plus**
  - **Excellent Dimensional Control & Surface Finish**

SSM: ADVANTAGES

- *Yet*, SSM Components are of Very High Integrity:
  - Sound, Heat-treatable, Good Mechanical Properties
  - Utilize High-integrity Alloys
    - Primary Alloys (A356, 354, 355, etc.)
      - Parts are Heat Treatable; T-5 (SSM Advantage) or T-6
      - Parts Have Good Strength/Ductility Combination
    - *Or,* Suitable Secondary (380, 333, 319, etc.)
      - Parts are Sound, Leak Free
    - *Or*, MMCs & Difficult-to-Cast Alloys (6061, etc.)
      - Special Properties

SSM - INHERENT ECONOMICS

- Near-Net-Shape
  - Minimum (or No) Machining
  - Material Thrifting, Minimum Material Content
  - Viscous Metal Flow, Minimum Turbulence & Multiple Cavities; Above & Below Metal Entry
- Low Energy Content During Casting
  - Long Tool Life (2 to 5 Times Die or Squeeze)
  - Fast Cycles
- T-5 versus T-6 Heat Treatment

SSM BILLET APPROACH

- **Billet Has Limitations**
  - **Supplied in Limited # of Alloys**
  - **Process Run-around Cannot be Reused for SSM w/o First Being Processed Back Into Billet**
- **Billet is thus an Expensive Approach**
  - **MHD Billet Sells at a Premium Over Similar-Alloy Foundry Ingot**
  - **Cost is often Viewed as Offsetting Inherent SSM Economic Advantages**
- **Billet Cost is Driving Development of *Slurry Concepts* & Other Alternatives**

SSM Slurry Alternatives

- Utilize *Normal Foundry Alloys/Forms*
- *Re-Use* In-Plant Process *Run-Around*

- Require only *Temperature Control* & *Sufficient Time* to Develop an Appropriate SSM Microstructure

SLC™

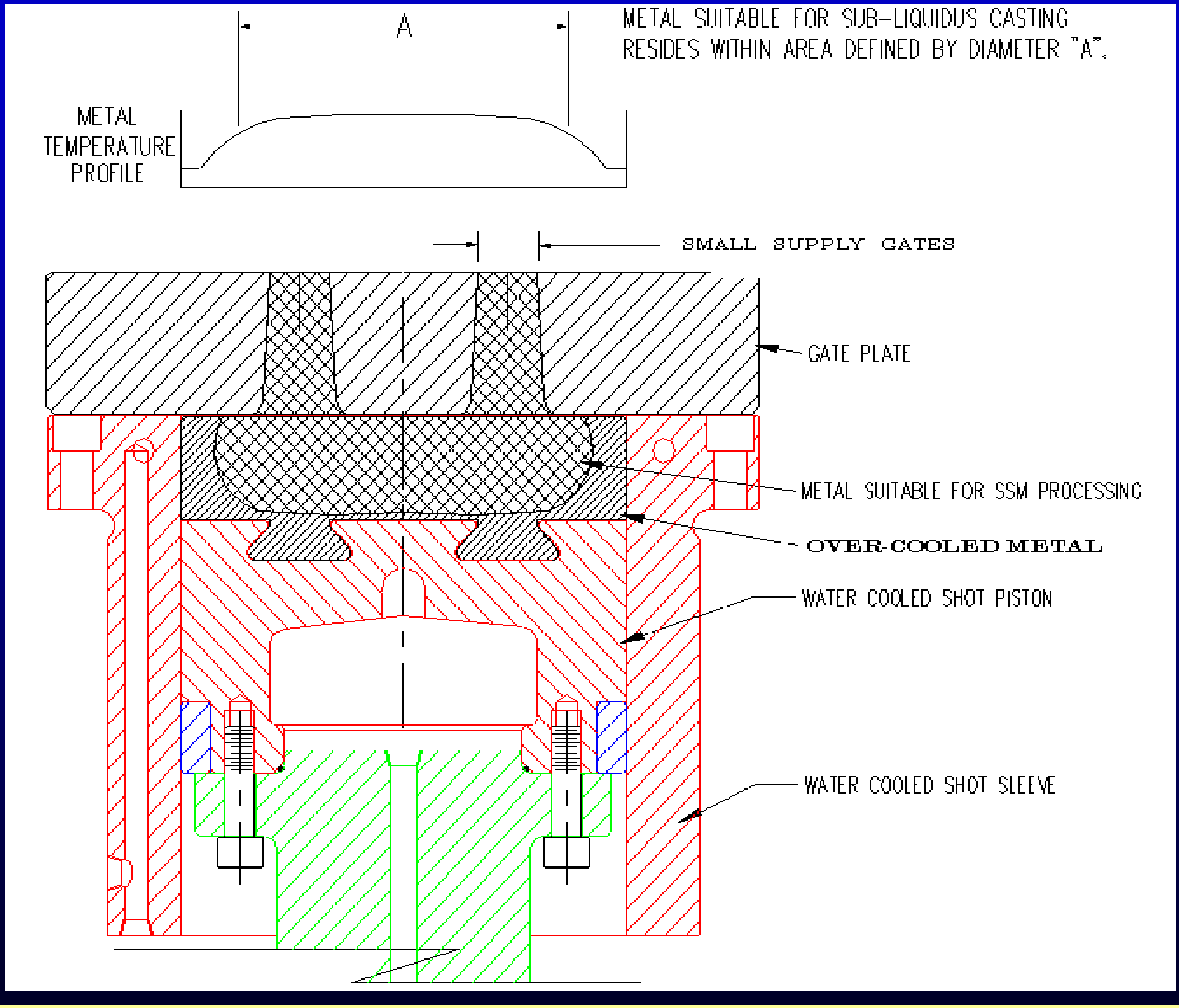
- SLC™ is a trademark of THT Presses, Inc., and stands for SUB LIQUIDUS CASTING

- Throughout this presentation, it will be referred to merely as SLC

SLC
SUB LIQUIDUS CASTING

- **SLC** is a *Slurry* Process
  - Uses Foundry Ingot & Re-uses Run-Around
- Introduced by THT Presses, Inc. in 2001
  - Combines Existing Equipment Designs
  - With Grain Refined Melt and Proper Temperature Controls
- Requires no Pre-Development of Slurry or Billet
  - No Processing of Slurry Outside of the Casting Machine or Normal Casting Cycle

SLC CONCEPT



A
METAL SUITABLE FOR SUB-LIQUIDUS CASTING RESIDES WITHIN AREA DEFINED BY DIAMETER "A".
METAL TEMPERATURE PROFILE
SMALL SUPPLY GATES
GATE PLATE
METAL SUITABLE FOR SSM PROCESSING
OVER-COOLED METAL
WATER COOLED SHOT PISTON
WATER COOLED SHOT SLEEVE

SLC Advantages

- Breakaway gates
- Less sensitive to:
  - Microstructural effects on properties
    - SDAS, mixed microstructure, low temp phases
  - Metal flow in die cavity and entrapment of bubbles
  - Directional solidification
- Less thermal input to die (~50% less)
  - Longer tool life (2 to 5 times)
  - Quicker solidification

What Makes SLC Work?

- ***SLC Requirements***

- **Grain Refinement**
- **Melt Temperature**
- **Melt Cooling in Shot Sleeve**
- **Time to Develop Slurry Structure**
- **Melt Flow into Die cavity**

SLC Requirements

- ***<u>Grain Refinement</u>***

- ***Good*** **Grain Refinement:**
  - **slurry structure developed in <u>seconds</u>**
  - **5:1::Ti:B, OK; TiBloy, better; SiB_2, best**
- ***Poor*** **Grain Refinement:**
  - **slurry structure developed in <u>minutes</u>**
- ***No*** **Grain refinement:**
  - **<u>cannot make casting</u>**

SLC Requirements

- ***Melt Temperature** (in furnace)*

- **Ideal:**
  - temperature 1-2° C above liquidus
- **Practical:**
  - temperature 5-10° C above liquidus

SLC Requirements

- ***Melt Cooling in Shot Sleeve***

- **Goal:**
  - **Achieve *40 to 60 % solid* in melt shot into die**
  - **Achieve *largely globular* structure**
  - **Achieve *majority* of melt suitable to shoot into die cavity (minimum amount over-cooled)**

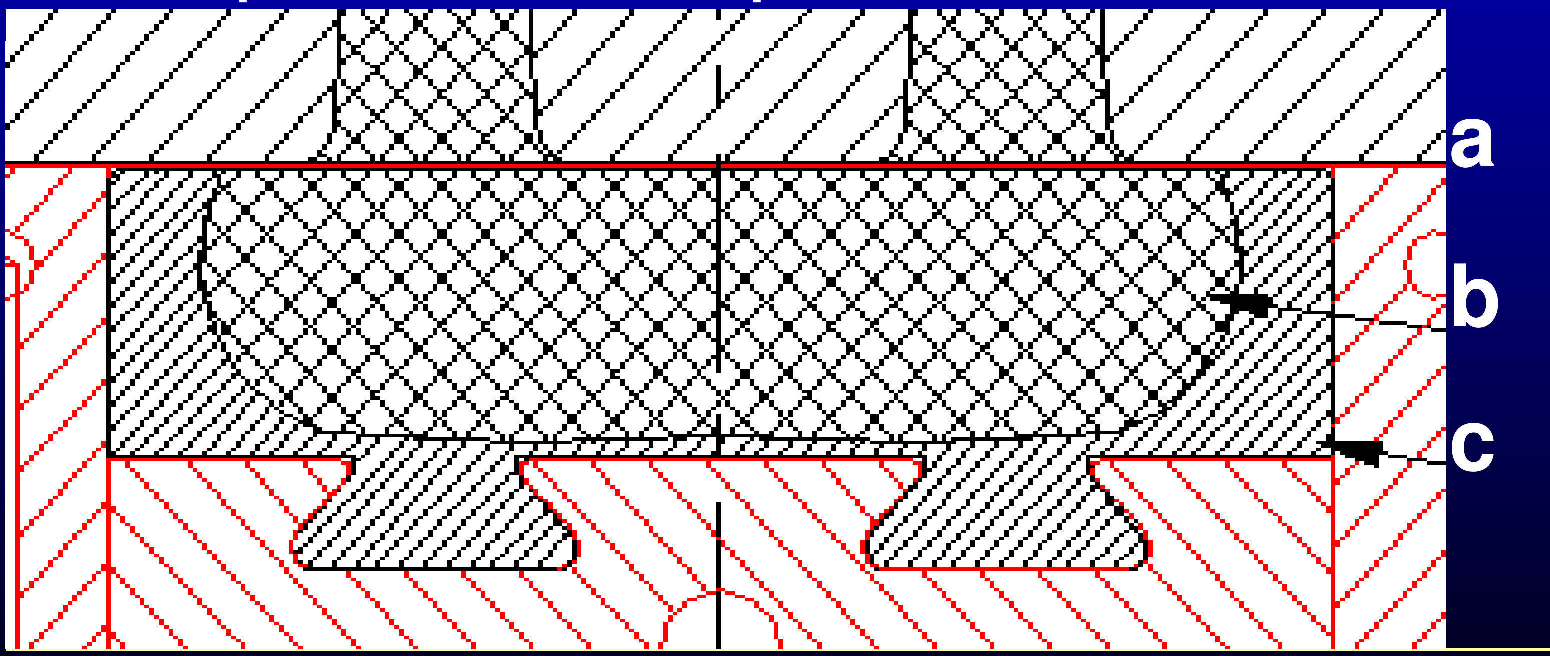
SLC Requirements

- ***Melt Cooling in Shot Sleeve***

- ***Large diameter/shallow shot sleeve is "ideal"*;**
- **small diameter/deep shot sleeve does not work w/o slurry heating and temperature stabilization time external to casting machine and casting cycle**

SLC Requirements

- Ideal Melt Cooling in Shot Sleeve
  - "a" 40% solid; "b" 60% solid; "c" 60-100% solid
  - Requires shot sleeve & piston thermal controls



SLC Requirements

- ***Time to Develop Slurry Structure***

- **Most difficult aspect of SLC concept to comprehend:**
  - **Frame of reference is billet experience**
  - **Cooling from liquid quite different from heating from solid**

SLC Requirements

- ***Time to Develop Slurry Structure***
- **Cooling from liquid:**
  - **Develop alpha structure and suspend cooling mid-solidification (just above eutectic temp.)**
    - **Small developing grains *quickly* become globular**
- **Heating from solid:**
  - **Melt eutectic and hold**
    - **Already developed dendrites *slowly* become globular**

SLC Requirements

- ***Time to Develop Slurry Structure***
- **The Goal: Achieve semi solid metal flow characteristics**
  - **viscous flow; stable metal flow front; rapid die fill without entrapped gas/oxides; *therefore* high product integrity; heat treatable; reliable**
- **Requires only a *largely* globular structure**
  - **size uniformity of globules not so important; decoupling is important; some decoupling likely occurs during flow to die**

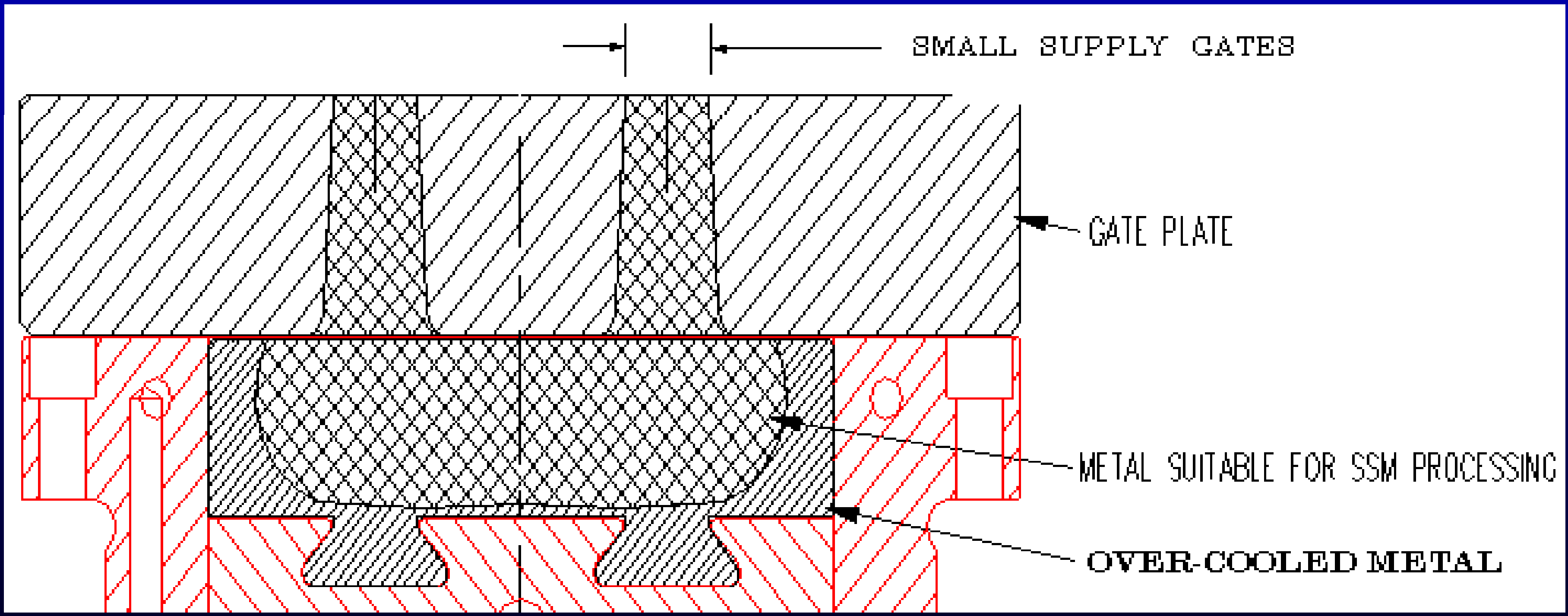
SLC Requirements

- ***Melt Flow Into Die Cavity***

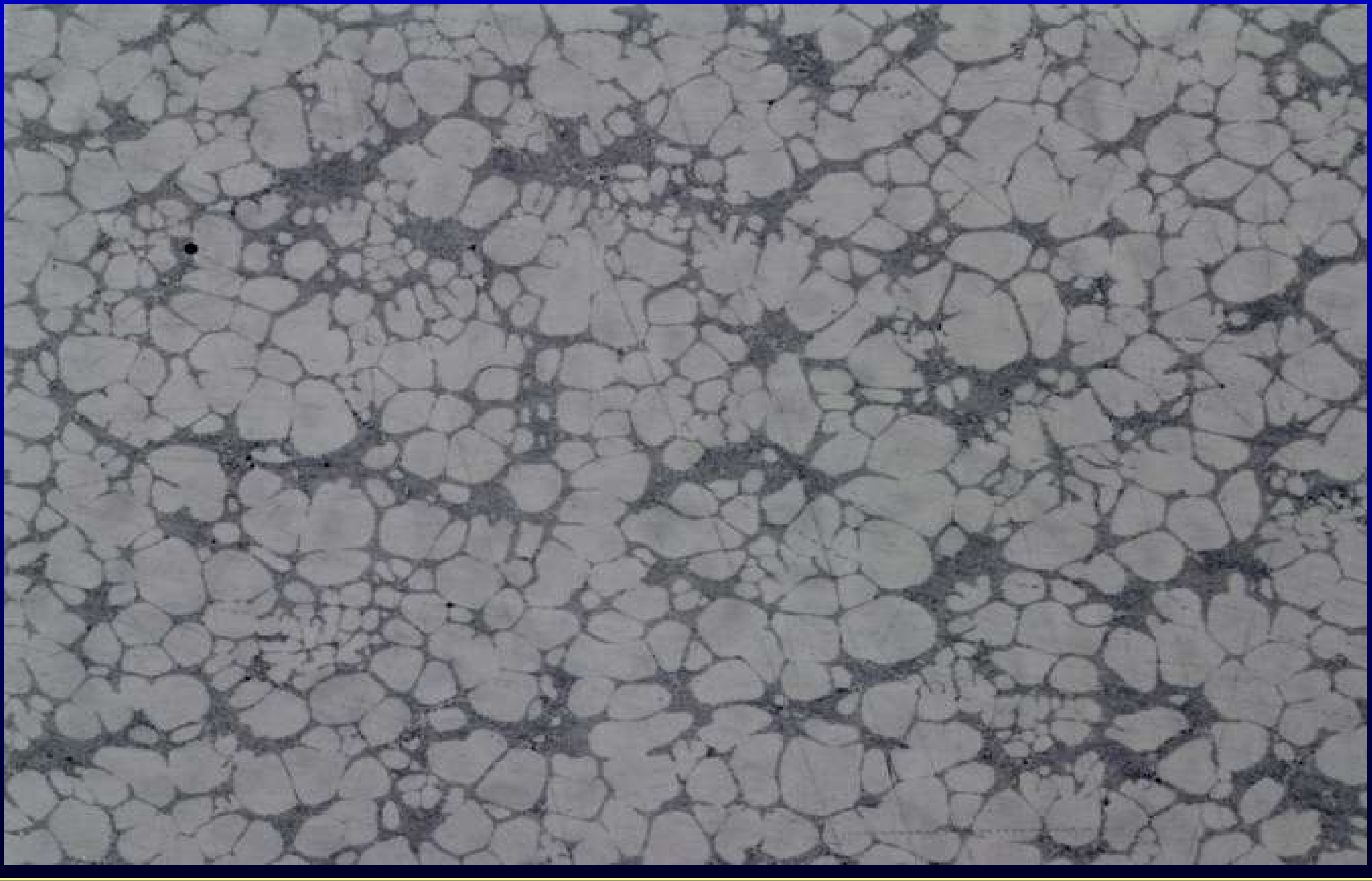
- **Only melt from 40-60% solid region of shot sleeve is directed into die cavity**
- **Balance remains in biscuit**

SLC Requirements

- ***Melt Flow Into Die Cavity***



SLC A356 MICRO



SLC Product Examples

- Have Produced: Knuckles, Control Arms, Valve Bodies, Torque Converters, Heat Exchangers, Disc Brake Rotors and Calipers, Transmission Pump Parts and Transmission Input Housings
- Using Alloys: A356/357, A354, 319, 333, 380, Zn, MMCs (and others)
- Will Relate Properties of: Steering Knuckles (A356) & Clutch Input Housings (333).

Chemistries of Alloys Cast

Alloy	Si %	Fe %	Cu %	Mn %	Mg %	Zn %	Ti %
A356 (pri)	6.9	0.13	0.07	<0.1	0.42	0.08	0.12
333 (sec)	9.61	0.68	3.56	0.25	0.31	0.47	0.06

Crucible Furnace in 100T SLC Casting Cell

Manual Shuttle Machine

SLC Casting Sequence

- Ladle melt to shot sleeve
- Shuttle mold/gate plate into position
- Make shot; typical 40-60+ ips velocity
- Solidification dwell (seconds)
- Withdraw piston, break gates free
- Open die; eject parts, remove biscuit
- Lube die, refill shot sleeve and repeat

Earliest SLC Knuckle Tests (at time of preparing paper)

- A356 variant (super grain refinement)
- Few castings and tests, provided merely an indicator of properties
- Tool was designed for squeeze casting, was not ideal SLC gating
- Compared to "typical" squeeze and low pressure

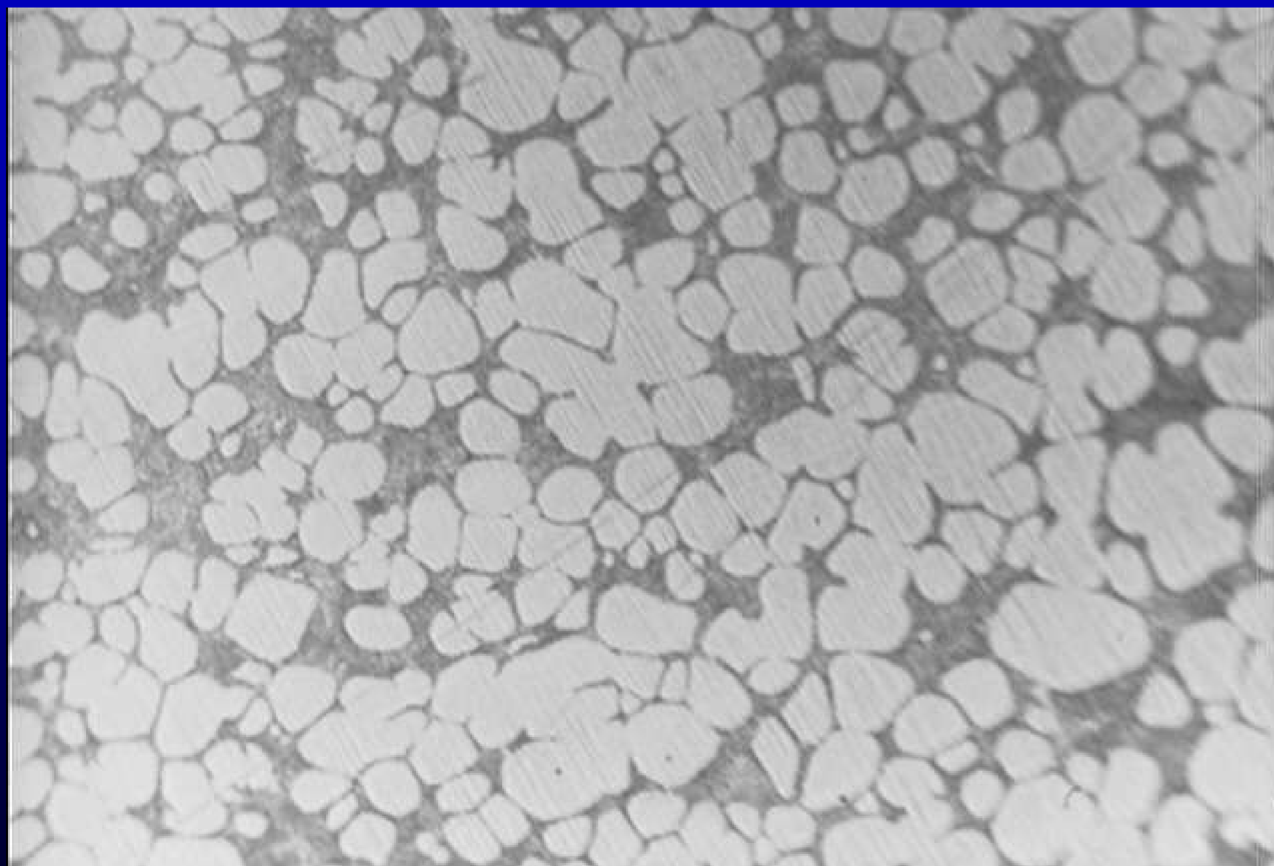
A356 Alloy Tensile Properties; Earliest SLC Knuckle Tests

	SLC					
	as cast	unquenched	quenched		Squeeze	Perm Mold
	F	T-5	T-5	T-6	T-6	T-6
UTS (MPa)	235	280	310	340	305	280
YS (MPa)	120	190	220	260	235	225
% El.	12	12	12	12	12	10

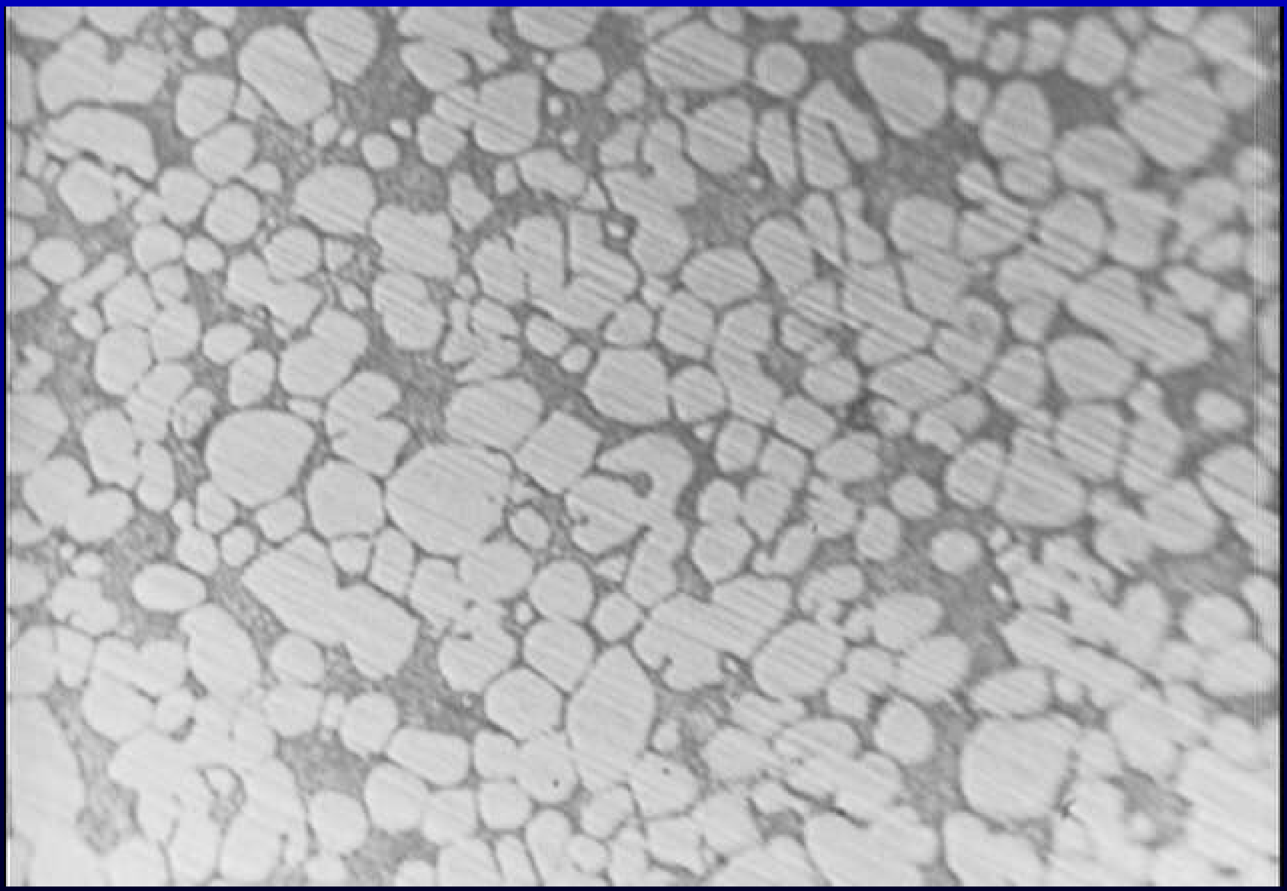
A356 Alloy Properties; Current Knuckle Expectations

- SLC properties equal or superior to Squeeze and Low Pressure
- T-6 tensile property expectations:
  - UTS > 280 MPa (290-320)
  - YS > 220 MPa (230-250)
  - El > 8% (10-16)

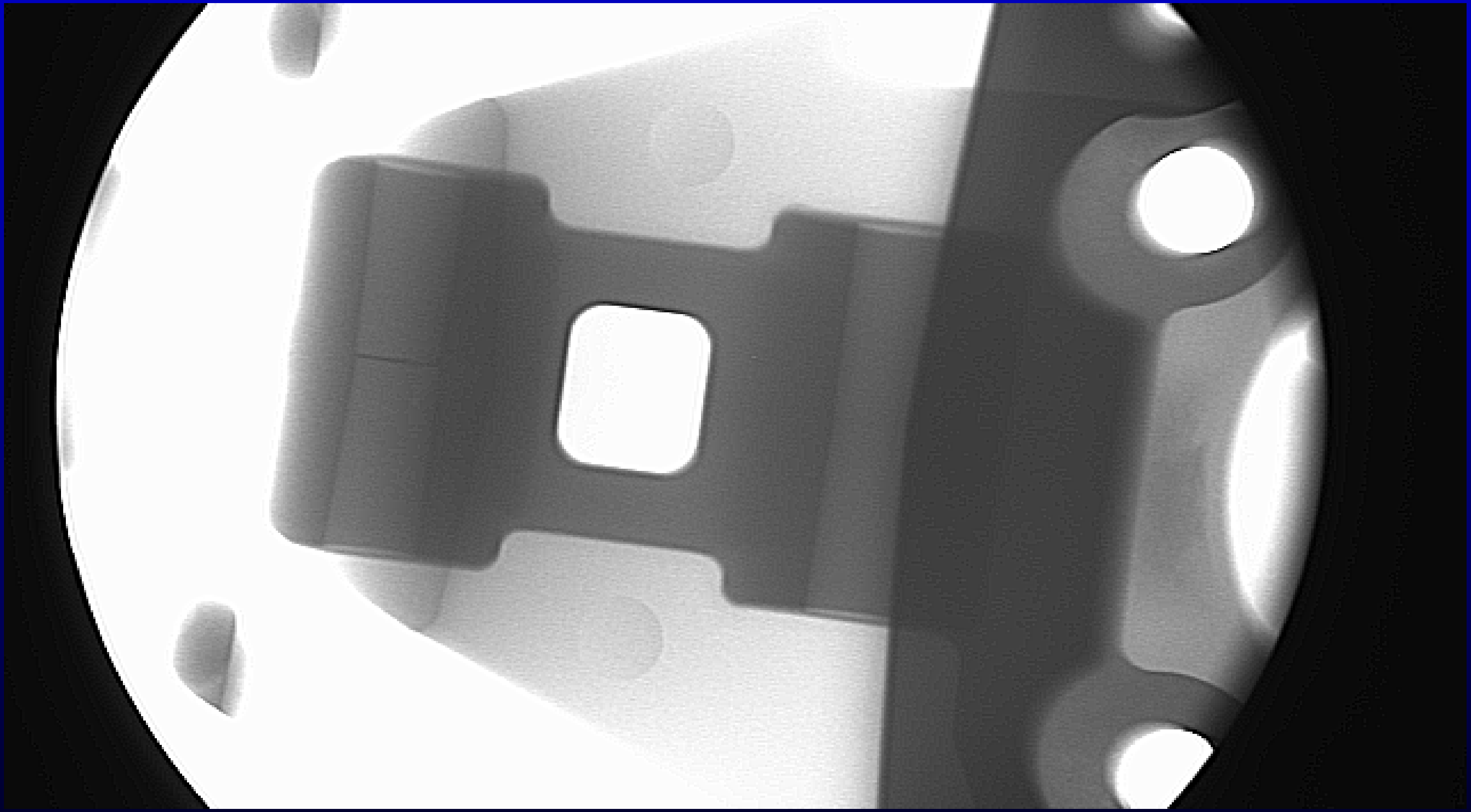
Typical A356 Alloy SLC Micros - 100X



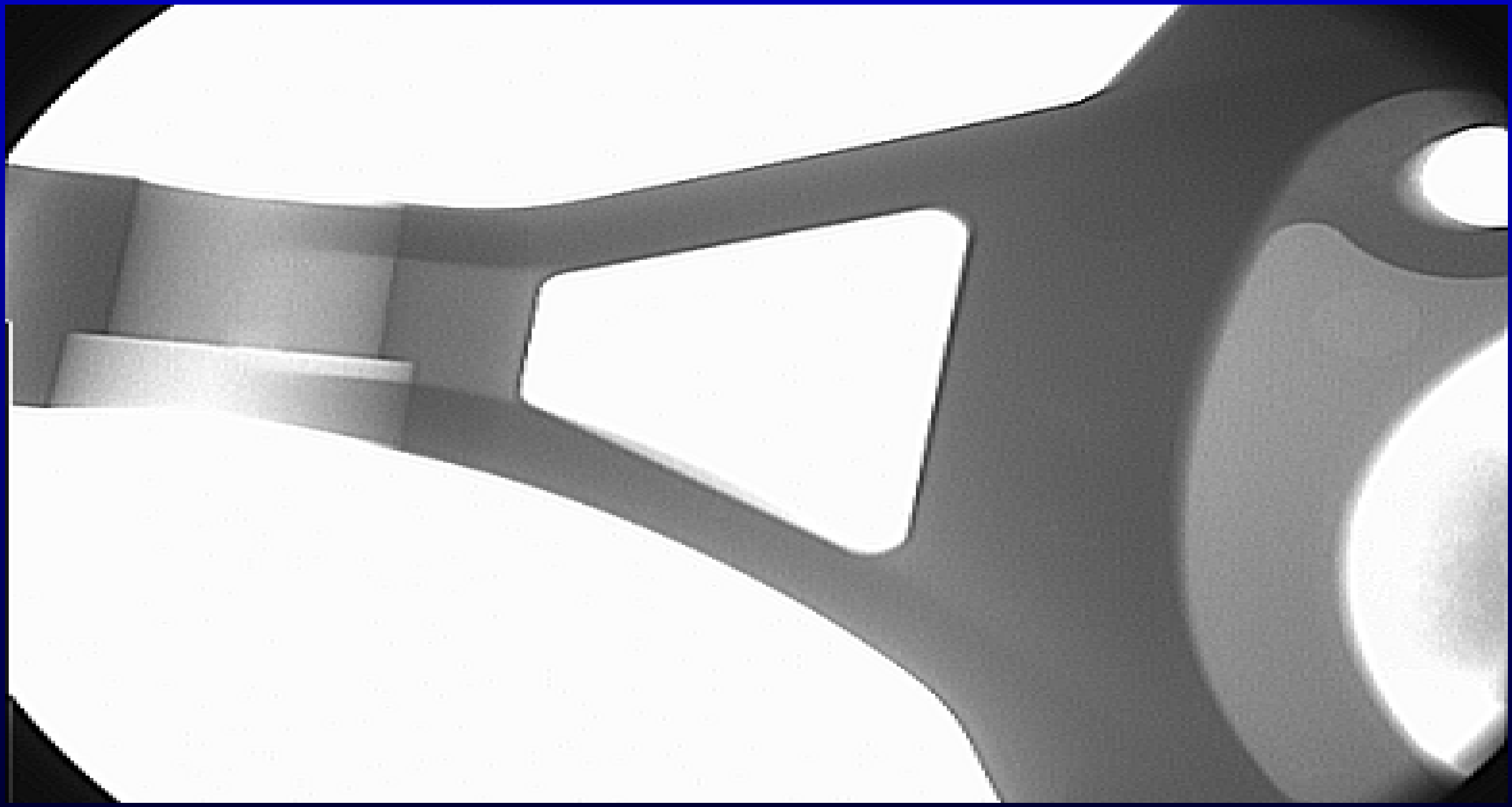
Typical A356 Alloy SLC Micros - 100X



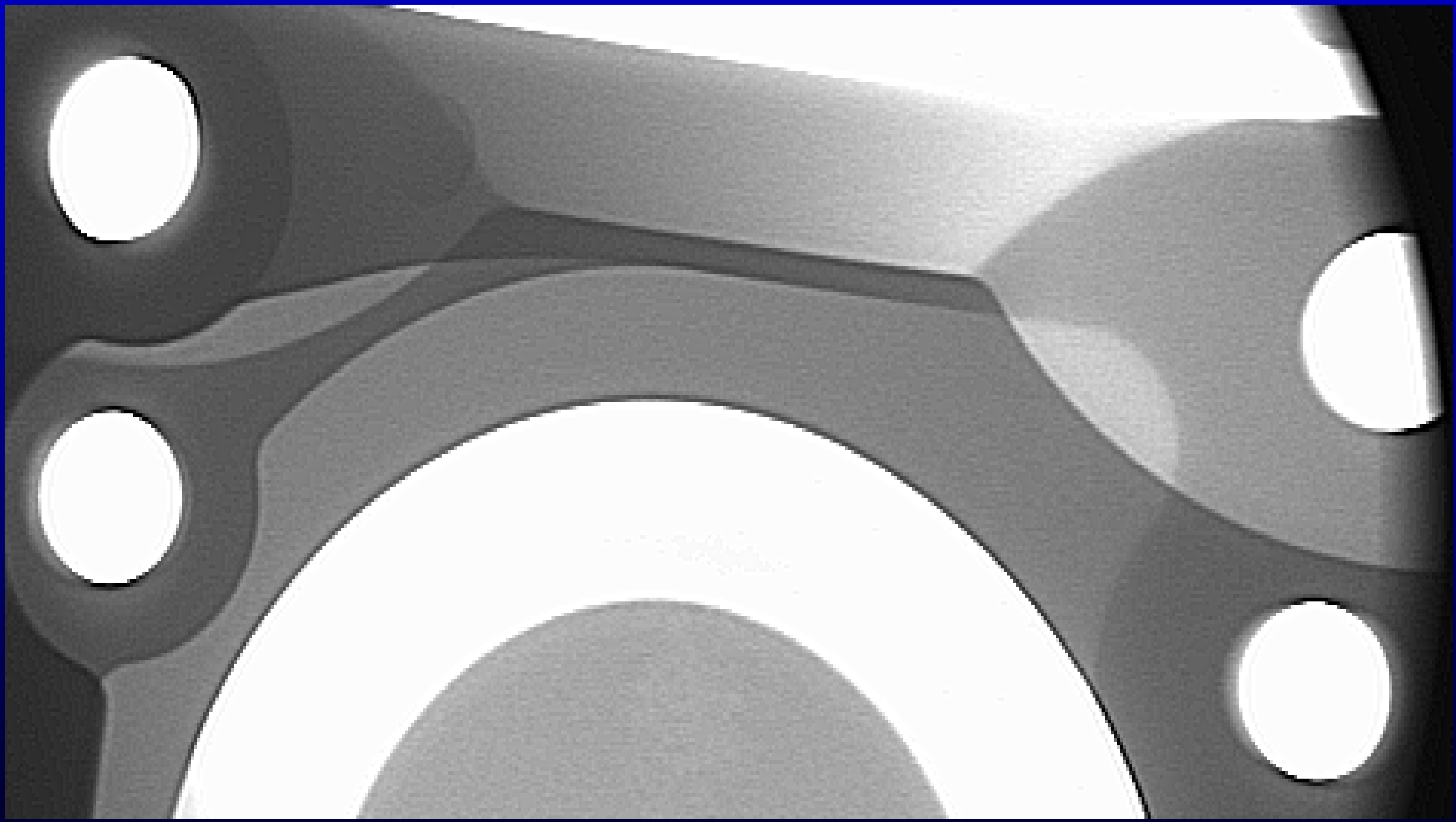
Typical SLC X-ray Quality



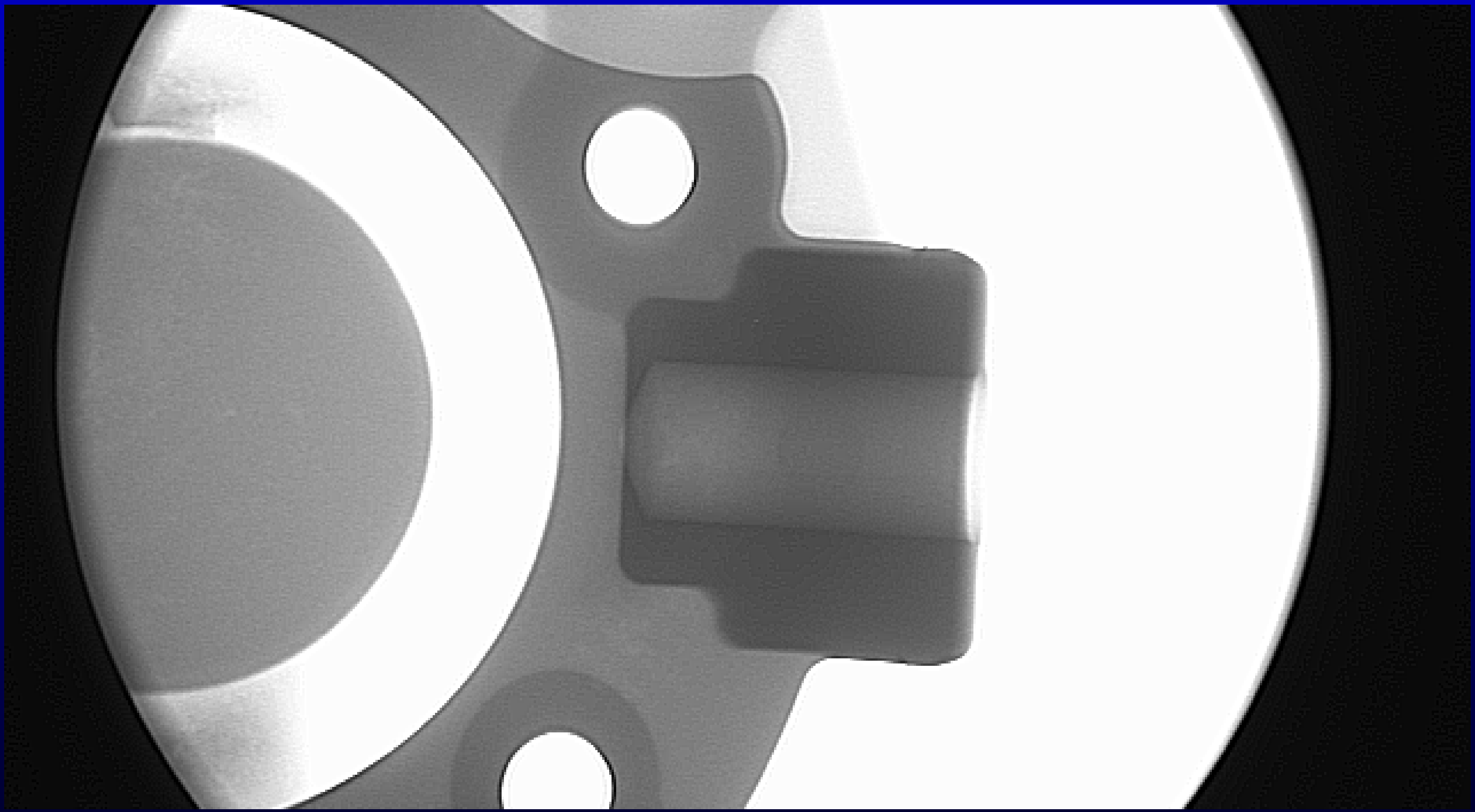
Typical SLC X-ray Quality



Typical SLC X-ray Quality



Typical SLC X-ray Quality



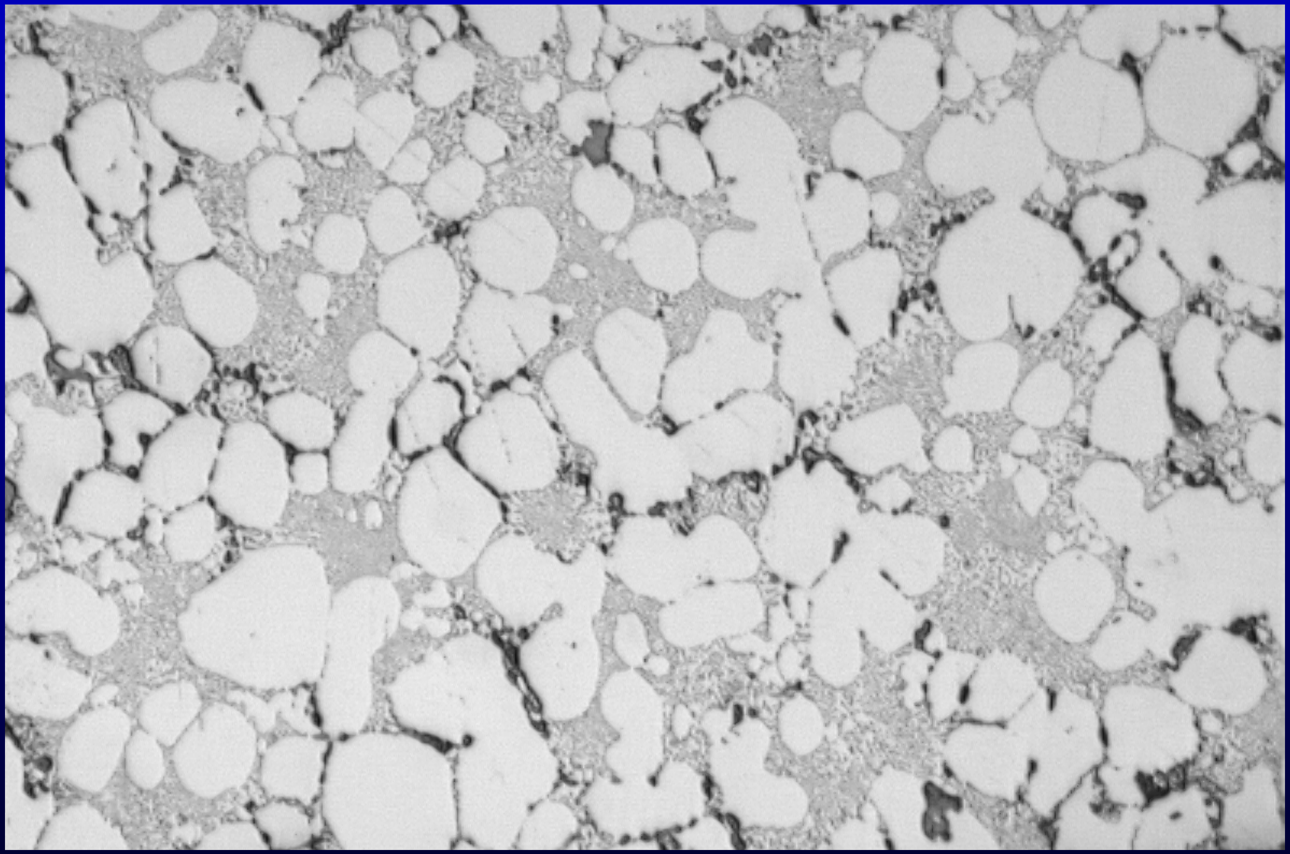
SLC Knuckle Properties

- Ave T-5 (quenched from the die):
  - UTS 270 MPa, YS 155 MPa, El 13+%, BHN 75+
- Ave T-6:
  - UTS 310 MPa, YS 248 MPa, El 14+%, BHN 100+

Clutch Housing

- Conversion from Permanent Mold
  - Closer to Net Shape
    - Ability to cast thin sections
    - Reduced machining
  - Multiple Cavity
  - Fast Cycles (< 1 minute)

333 (380–type) Alloy
SLC Micro – 100 X



About 333 SSM (SLC)

- Not an Ideal SSM Candidate
  - Only 30-35% solid at processing temperature (vs ~50% in 356-type)
- Still, it fills well and makes sound parts

333 Tensile Properties

	SLC	SLC	**P.M.**
	As Cast	T-5	**T-6**
UTS (Mpa)	215	285	**230**
YS (Mpa)	160	210	**180**
% El	6	6.5	**1**