



Controlled Cooling Effects

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Controlled Cooling Effects

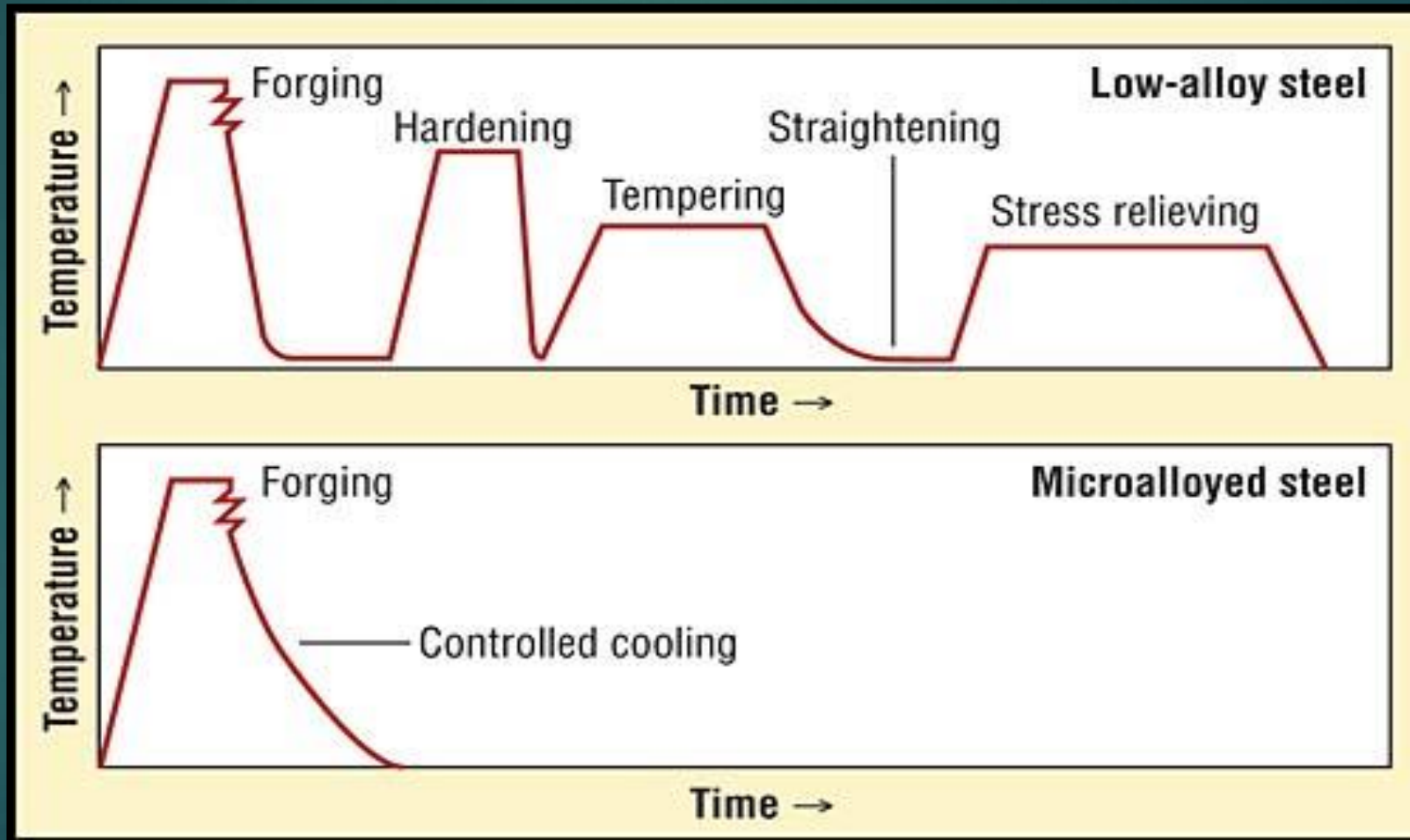
MICROSTRUCTURAL ANALYSIS OF

- CRANKSHAFT
- CONNECTING ROD
- STUB AXLE

Controlled Cooling

- ▶ Controlled cooling - an alternative (and superior) process to conventional heat treatment.
- ▶ Utilizes the heat from the hot forging process for ***successive stress relieving process***.
- ▶ Micro-alloyed steels yield best results after controlled cooling.
- ▶ Mechanical properties ***identical*** to hardened and tempered component
- ▶ Compromises on the ***toughness*** of the component.

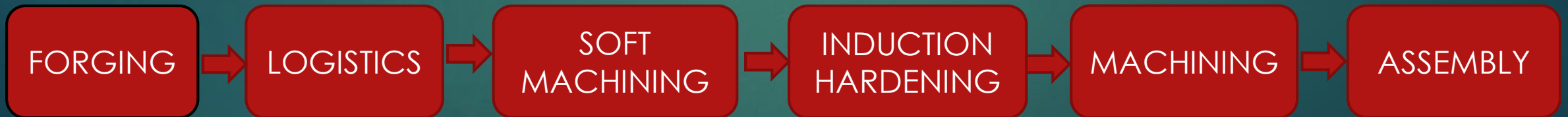
Controlled Cooling



Crankshaft 497

- ▶ Micro-alloyed steel used (38MnSiVS5).
- ▶ Reference code SAE1541.

Processing Cycle

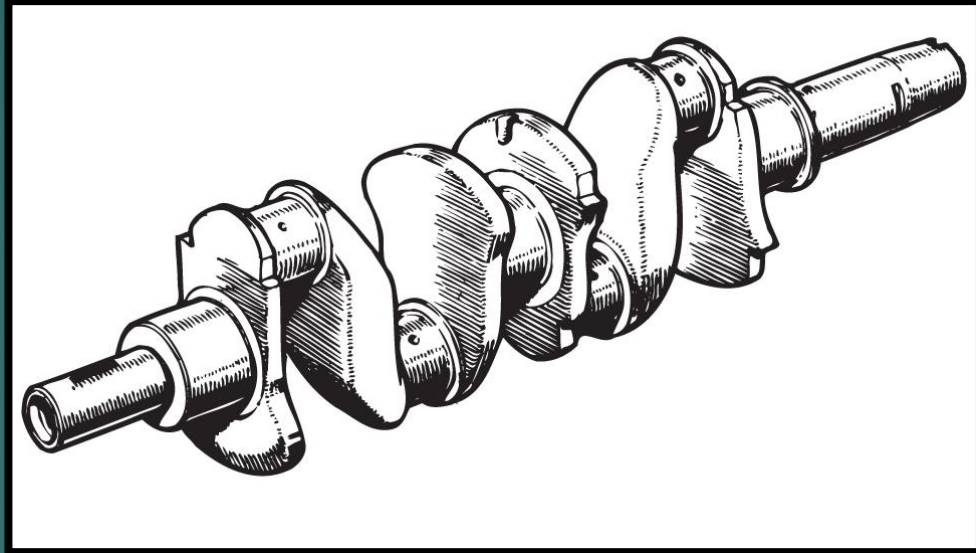


Crankshaft 497

Control cooled
Crankshaft at
TML Pune

Ahmednagar
Forgings Ltd.
(formerly Neepaz
Forge) (AFL)

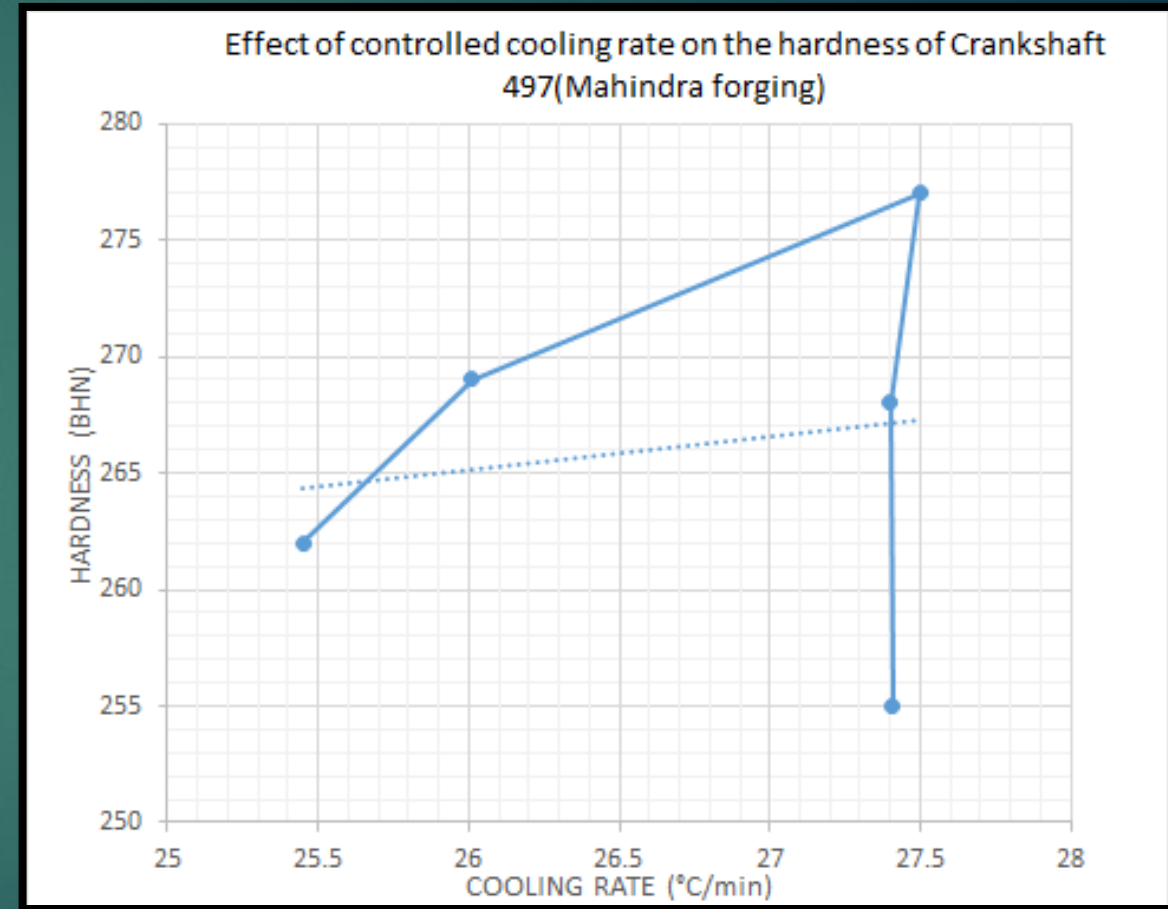
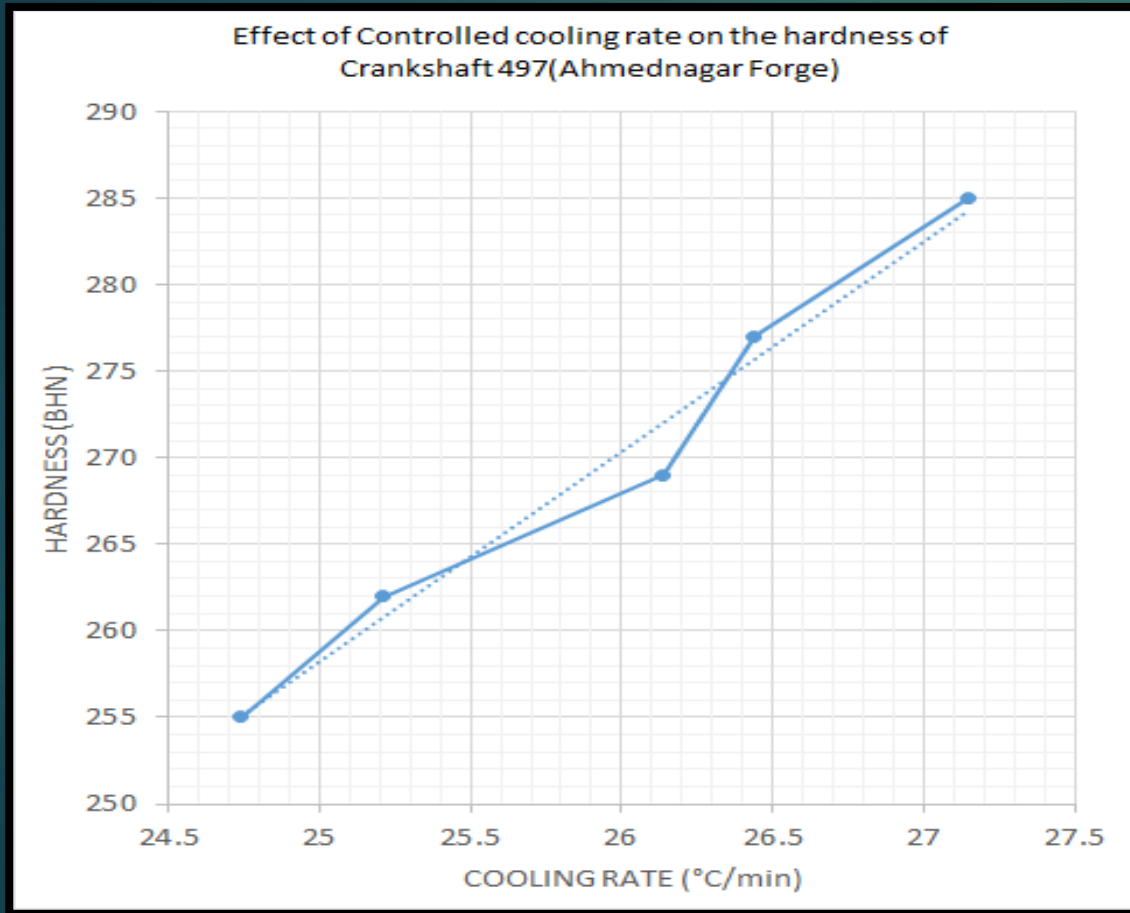
Mahindra
Forgings Ltd.
(MFL)



Process Parameter Comparison

Sample	Conveyor Length (m)	Travel Time (min.)	Cooling Setup	Avg. Cooling Rate (°C/min)
AFL	16	23	4 fans (1430 rpm)	25
MFL	13.38	22	3 fans (off)	26.5

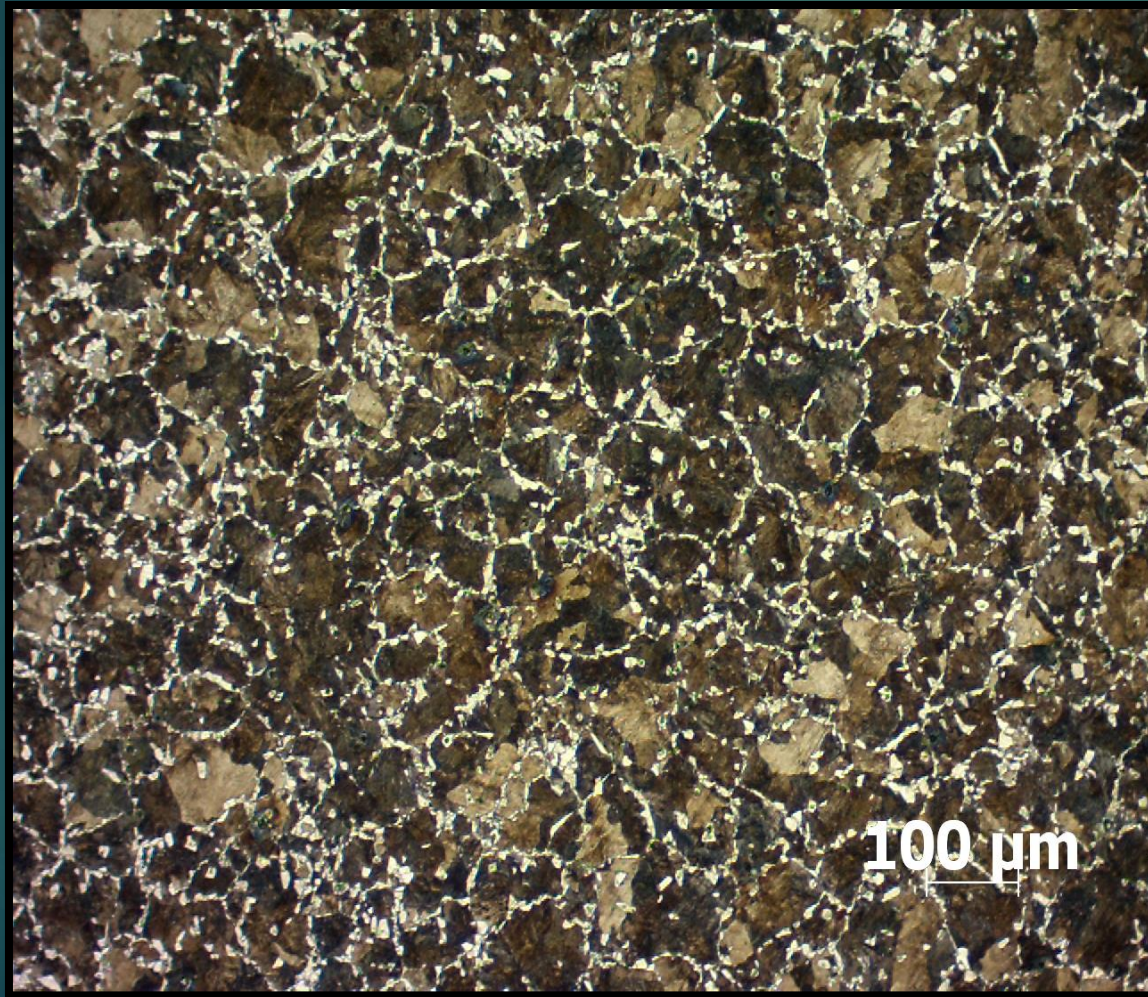
Hardness Comparison



The hardness is seen to increase with increasing cooling rate owing to finer grain size.

Microstructure Comparison

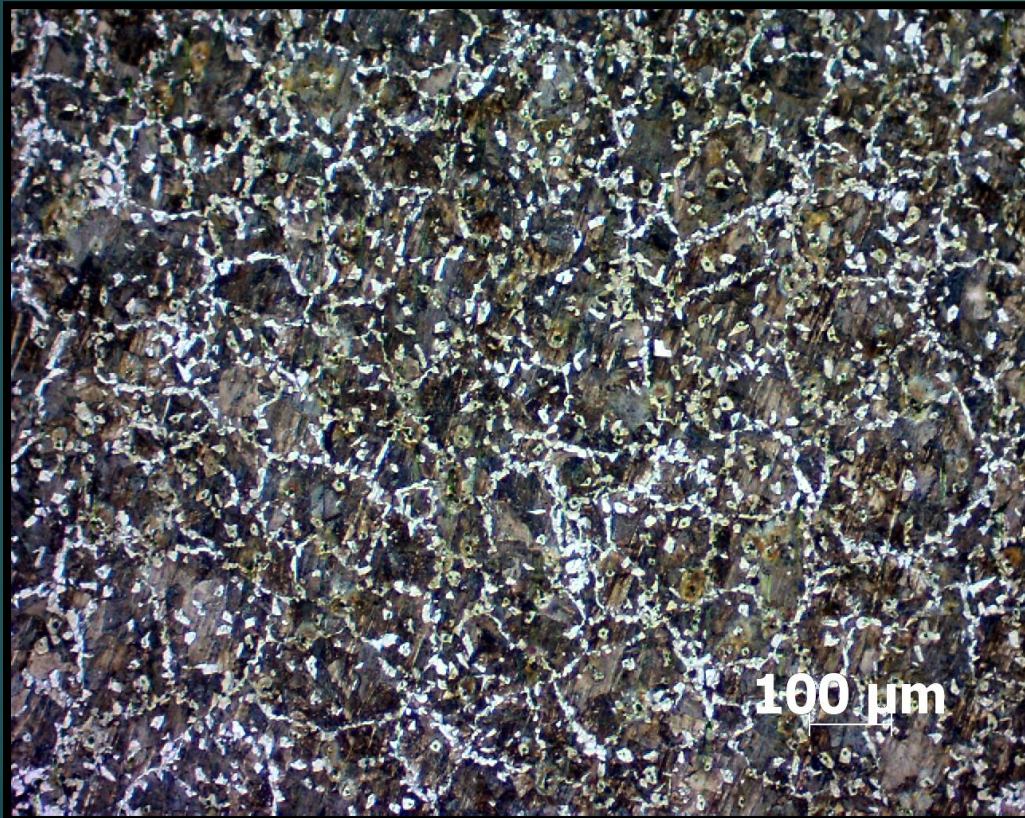
► Crankshaft 497 (AFL)



- Grain Size - 5 ASTM.
- Uniform ferrite and pearlite distribution
- Ferrite present along the grain boundaries (~3.5%).
- Relatively thin and continuous grain boundary.
- Minor decarburization also observed.

Microstructure Comparison

► Crankshaft 497 (MFL)



- Grain Size ~4.5 ASTM.
- Uniform distribution of ferrite and pearlite with traces of *bainite*.
- Ferrite (~4.8%) present along the grain boundaries as well as within grains (circular white spots).
- Relatively thick and discontinuous grain boundary.
- No appreciable decarburization observed.

Fracture Split Connecting Rod

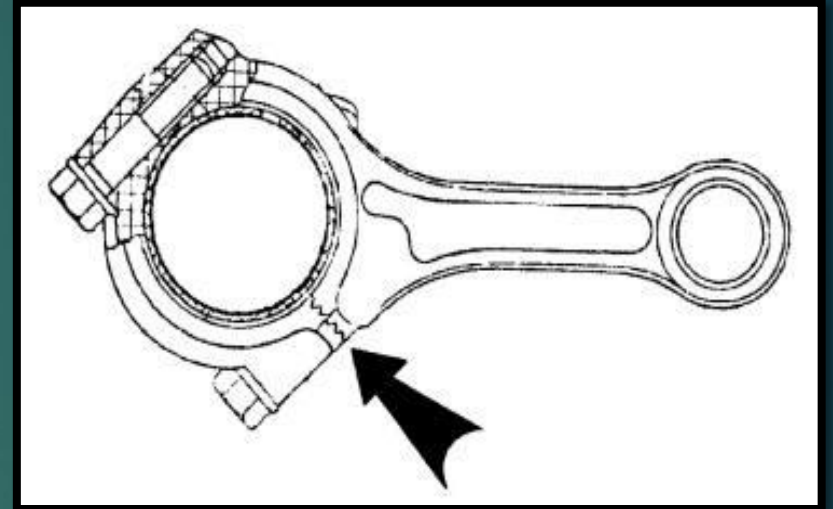
- ▶ Grade C70S6
- ▶ High Carbon content makes it brittle.
- ▶ Generic forging sequence:
 1. Reduction rolling
 2. Flattening
 3. Blocking
 4. Finishing
 5. Control Cooling

Connecting Rod 497 & 4SP (Fracture Split)

Controlled cooled
Con-rods at TML Pune

Varroc Engineering
Pvt. Ltd. (4SP)

Adico Forge (497)

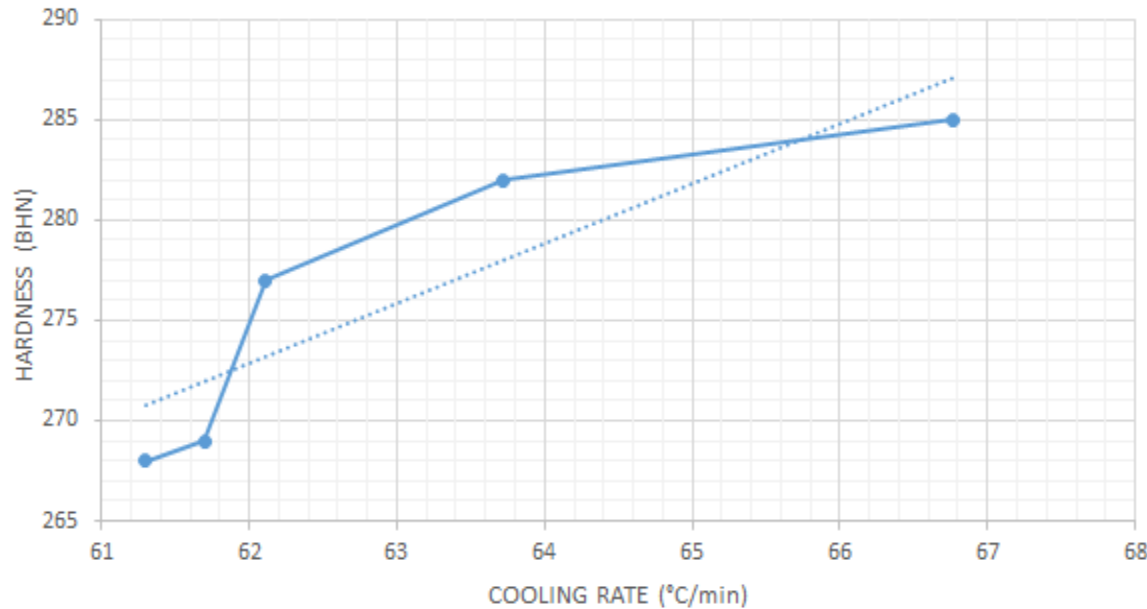


Process Parameter Comparison

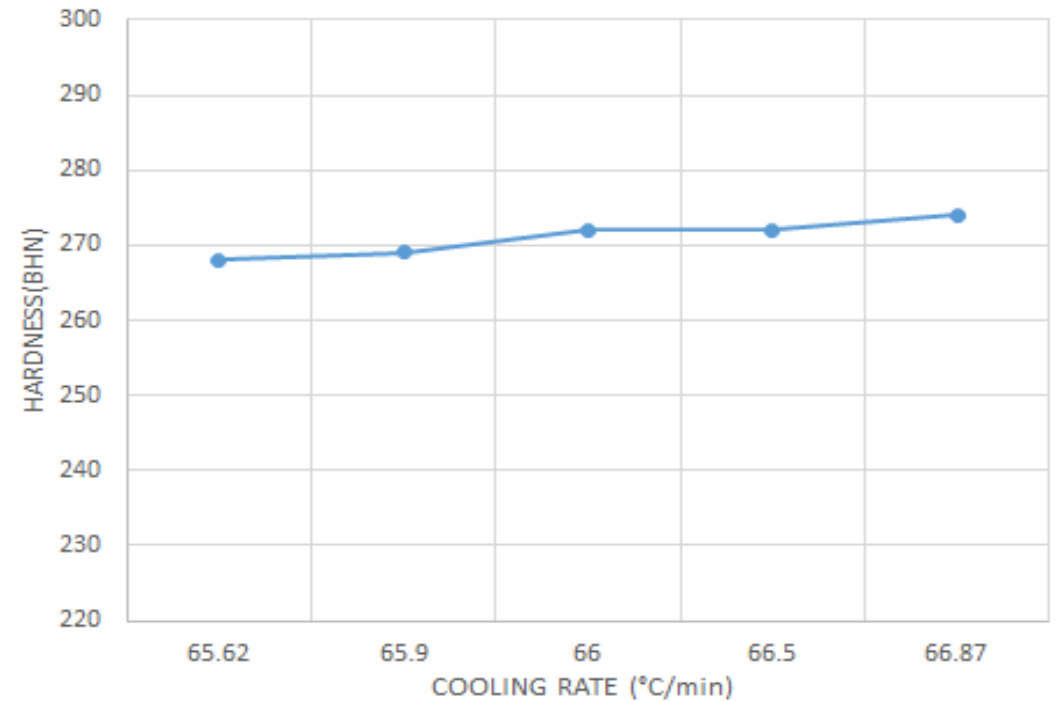
Sample	Conveyor Length (m)	Travel Time (min.)	Cooling Setup	Avg. Cooling Rate (°C/min)
Varroc Engineering (497)	16.5	8	2 fans (1500 rpm)	66.5
Adico Forge (4SP)	10	6	1 fan (1400)	64

Hardness Comparison

Effect of Controlled cooling rate on the hardness of Conrod 497 (Adico Forge)



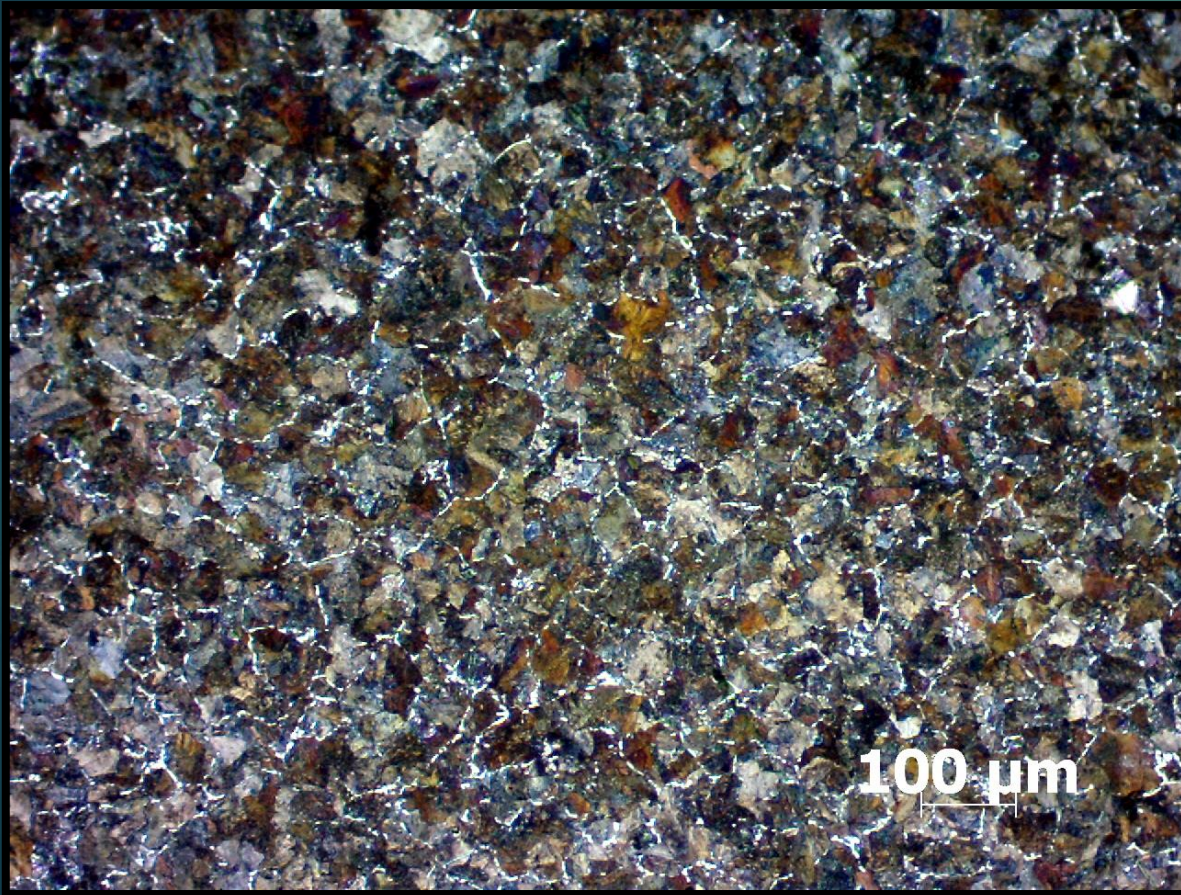
Effect of Controlled cooling rate on the hardness of Conrod 4SP (Varroc Forge)



As the cooling rates approach 70 °C/ min, hardness is seen to approach constant value.

Microstructure Comparison

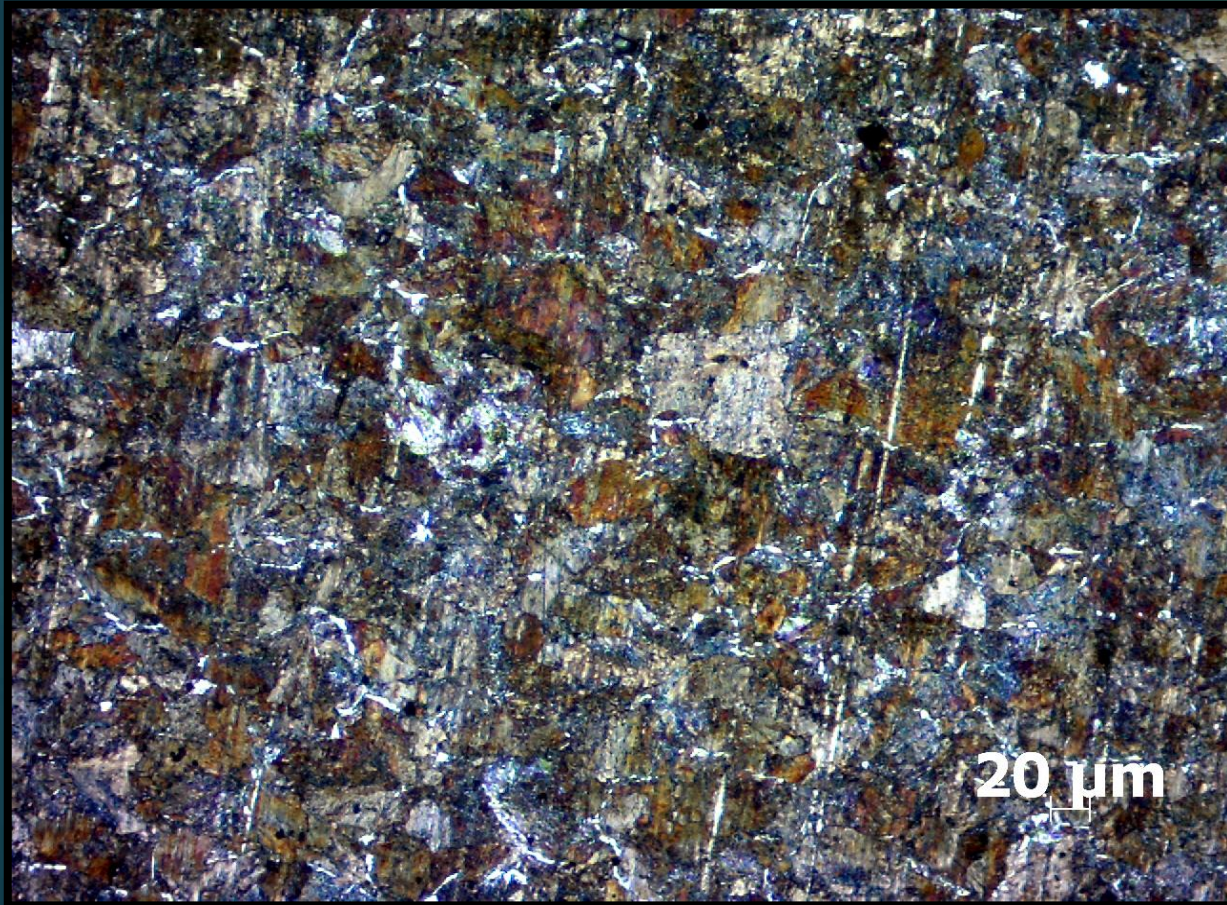
➤ Varroc Engineering (4SP)



- Grain Size 6-7 ASTM.
- Ferrite (~5 %) is distributed in a pearlitic matrix.
- Carbides (dark colored patches) are formed due to presence of micro-alloying elements (VC).
- No decarburization observed.
- Very thin grain boundary lining consisting of pearlite.
- Apart from ferrite and pearlite, various other micro-alloyed compounds can be observed (multi-colored areas)

Microstructure Comparison

➤ Adico Forge (497)



- Grain Size 7-8 ASTM.
- Ferrite ($< 5\%$, $\sim 4.1-4.2\%$) in a pearlitic matrix.
- Relatively less presence of carbides.
- No significant decarburization.
- Thinner grain boundary (due to lesser ferrite).
- Other micro-alloyed compounds can be observed (vividly colored areas).

Stub Axle (Sumo)

- ▶ Reference Grade SAE 1541
- ▶ Micro-alloyed steel used.
- ▶ Generic forging sequence:



Stub Axle (Sumo)

Sumo Stub
Axles at TML,
Pune

Mahindra
Forgings Ltd.

Ahmednagar
Forgings Ltd.

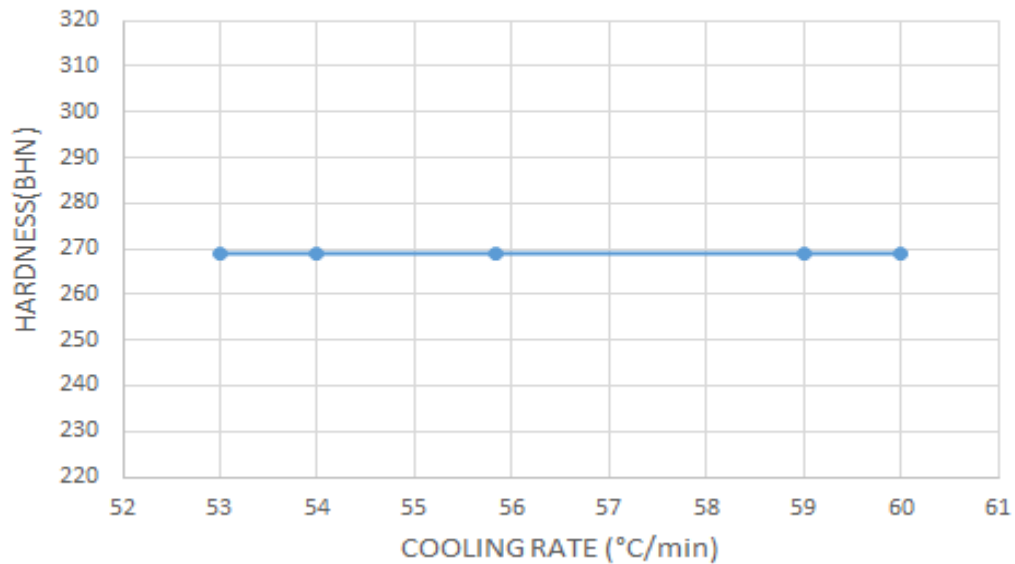


Process Parameter Comparison

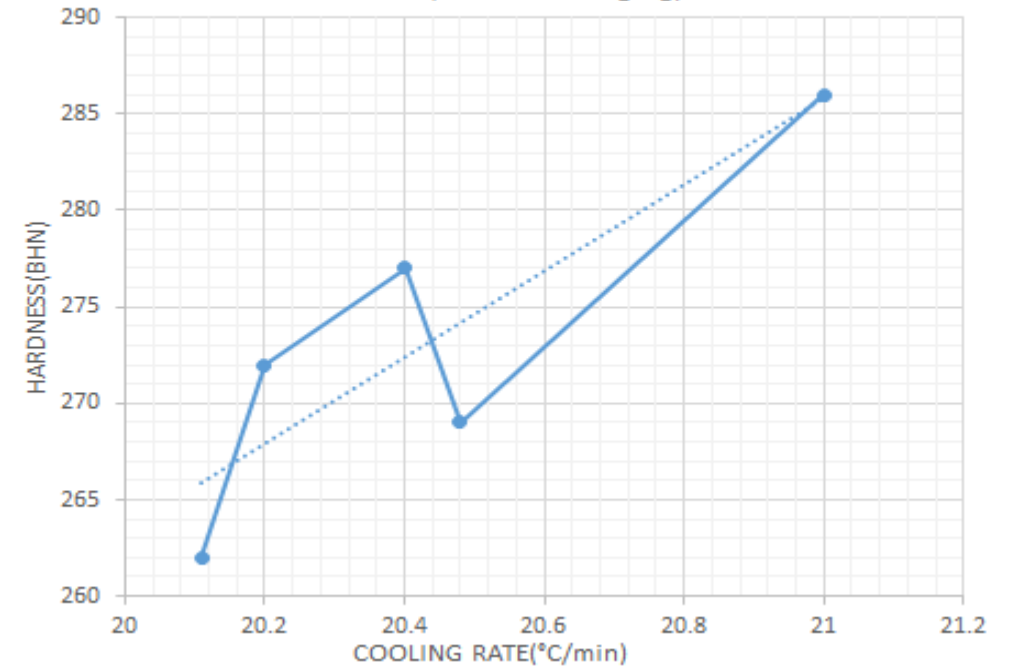
Sample	Conveyor Length (m)	Travel Time (min.)	Cooling Setup	Avg. Cooling Rate (°C/min)
AFL	7	12.5	4 fans (1430 rpm)	66.5
MFL	10	6	3 fans	64

Hardness Comparison

Effect of Controlled cooling rate on the hardness of Stub Axle (Ahmednagar Forging)



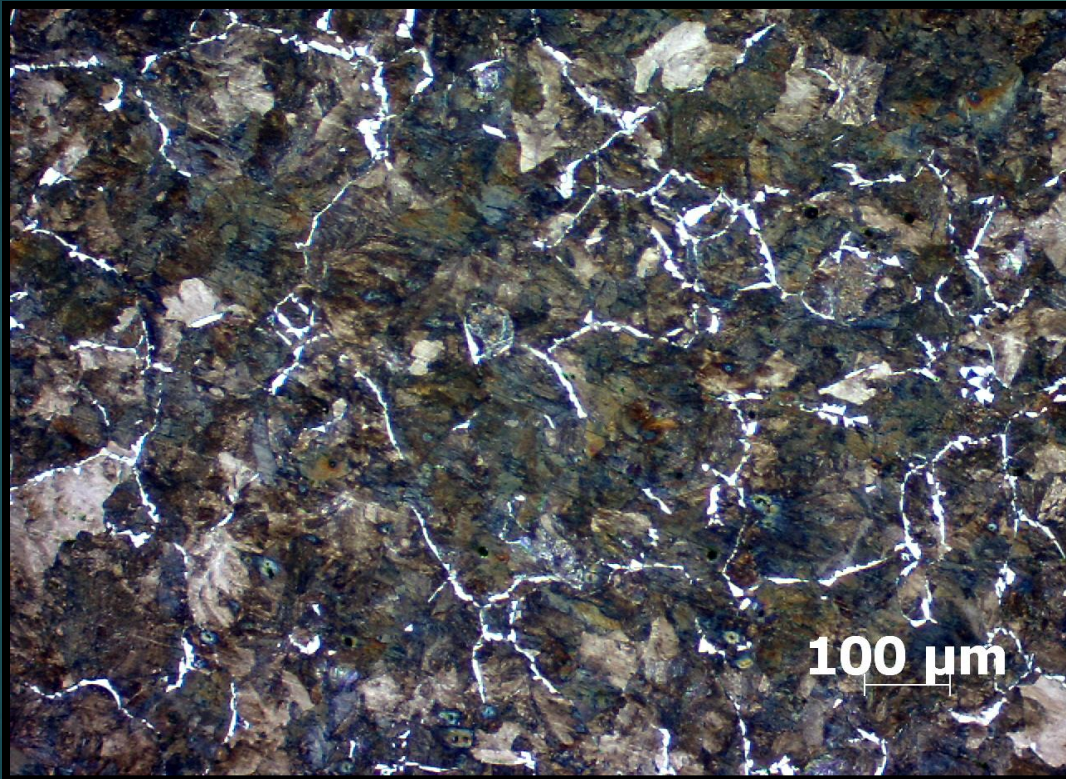
Effect of Controlled cooling rate on the hardness of Stub Axle (Mahindra Forging)



Cooling rates of approximately 50°C/ min and above gives a stable hardness .

Microstructure Comparison

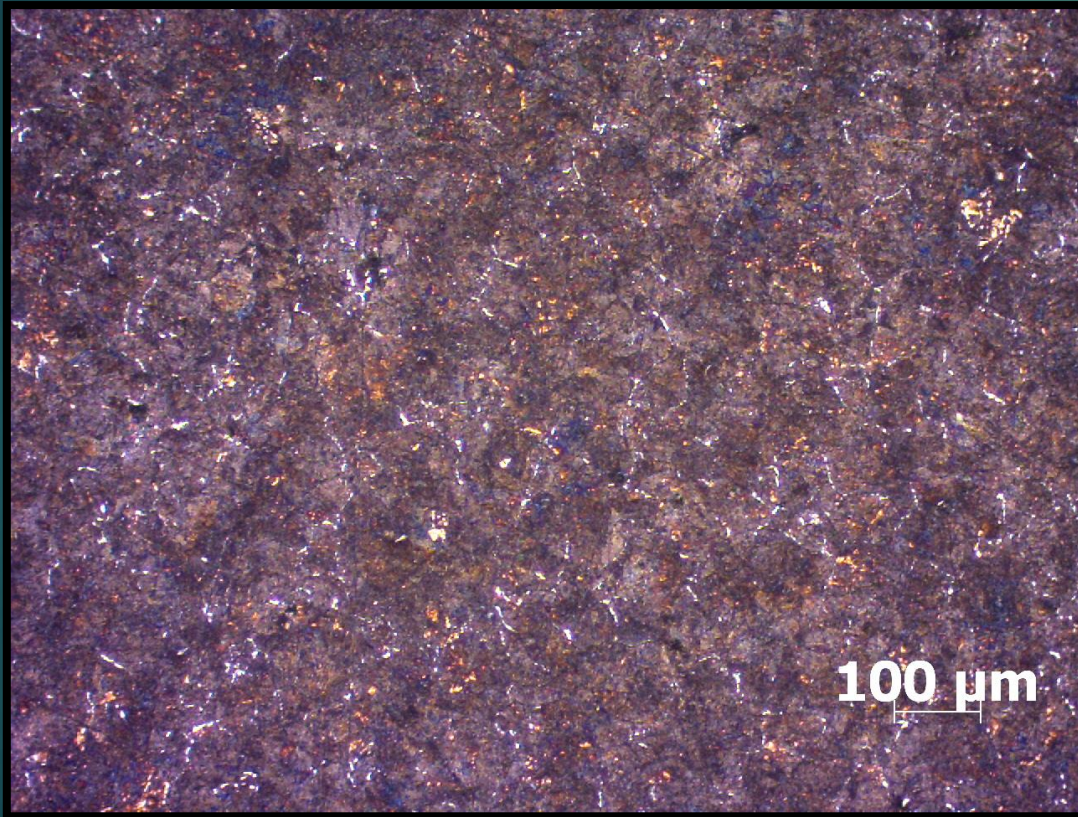
► Mahindra Forgings Ltd.



- Grain Size 5-5.5 ASTM.
- Ferrite (3- 5%) in a pearlitic matrix.
- Very less presence of carbides.
- No decarburization.
- Thick and discontinuous grain boundary.
- White grain like areas are non indicative of ferrite. These are due to light etching.

Microstructure Comparison

► Mahindra Forgings Ltd.



- Grain Size 6 ASTM.
- Ferrite (~3%) in a pearlitic matrix.
- Negligible carbide formation.
- No decarburization.
- Thin and discontinuous grain boundary.

Future Prospects

- ▶ Prediction of 'Critical Cooling Rate' for a particular component.
- ▶ Process re-design and optimization for achieving optimum hardness & desired microstructure
- ▶ However, rigorous process data analysis would be required.
- ▶ Sufficient samples would be required so as to infer microstructural consistencies or inconsistencies.