



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

Failure Analysis & Prevention

Fundamental Sources of Failure: Improper manufacturing conditions

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Manufacturing

- Includes sizing, shaping, finishing and imparting properties
- Realized through (use of heat and force)
 - Melting: casting,
 - Partial melting: fusion welding, machining (LBM, EDM)
 - Deformation:
 - Micro-deformation: USW, Explosion welding, diffusion bonding
 - Macro-deformation: rolling, forging, friction welding
 - Controlled heating and cooling: heat treatment

Common reasons for deficiency in manufacturing

- Unsuitable specification of procedure for manufacturing
- Incomplete or ambiguous specification
- Changes in specifications without proper evaluation
- Failure to follow specified procedure
- Operators inadvertent error
- Accidental damage



Unfavorable manufacturing processing conditions

- The selection of inappropriate combination of the process parameters for each of above mentioned manufacturing processes can lead to development of
 - discontinuities,
 - defects,
 - Unfavorable metallurgical changes
 - None-uniform mechanical properties and chemical compositionAll these can cause deterioration in the performance of final product during the service.



Manufacturing vs Mechanical Performance

- Manufacturing processes affect the microstructure of metal
- The microstructure in turn affects mechanical properties such as
 - Hardness
 - Strength
 - Ductility
 - Toughness
 - Fatigue
 - Creep resistance
- Therefore, such variations in mechanical properties must be kept in mind for ensuring that end product has requisite properties for service desired.



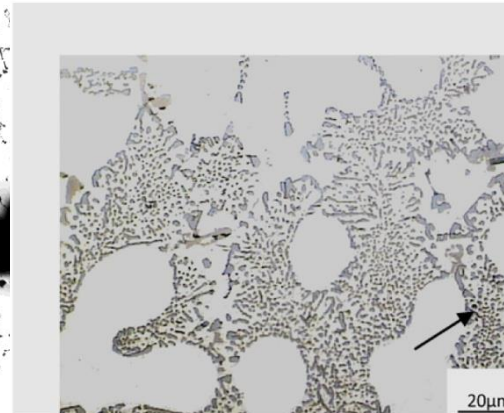
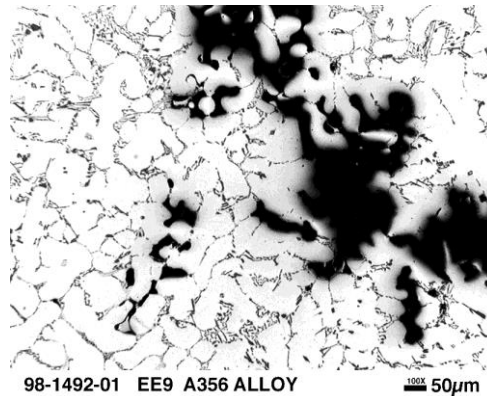
Melting based manufacturing

- Affinity with atmospheric gases: pores, inclusion, slag formation (degassing, fluxing, filtration)
- Segregation tendency: hot tears, heterogeneity in structure and mechanical properties, banded structure, coarse structure
- None-uniform cooling conditions: hard spot and soft zone formation
- Unfavorable solidification pattern: shrinkage porosity, porosity (chills/chaplets)
- Residual stresses, improper gating/riser designing



Casting

- Cast structure
- Poor in terms of hardness, strength, toughness and ductility
- Scope of internal defects
- Heterogeneity: in terms of composition and property



Welding

- Liquid state: cast weld metal, heat affected zone
- Solid state: affect the properties as per strengthening mechanism, weld nugget and HAZ
- Liquid-solid state: does not affect the base metal properties but joint strength is poor, brazed/soldered joint



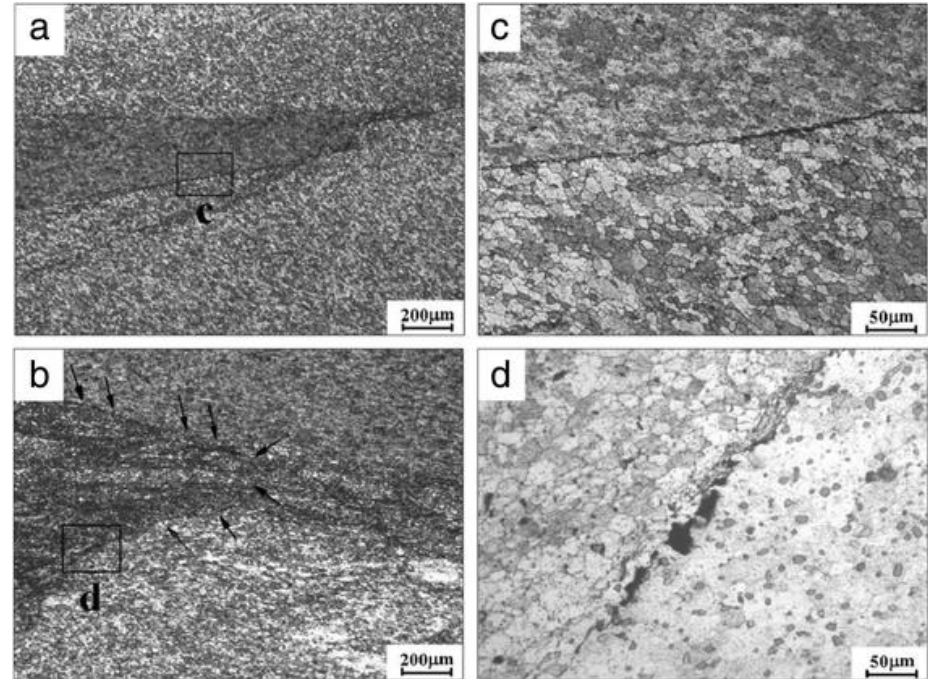
Fusion weld fabrication

- Partial melting: tensile residual stress, heat affected zone, liquation cracking
- Affinity with atmospheric gases: porosity, inclusion, delayed cracking due to H_2
- Cast structure: planar, cellular, dendritic, equiaxed,
- Alloy element segregation: solidification cracking
- None-uniform structure and mechanical properties
- Heat affected zone: cold cracking, underbead



Solid state joining

- Both micro/macro scale deformation: FSW, USW, DB
- Inclusions due to improper cleaning
- Limited metallurgical bonding due to lack of deformation and diffusion
- Hardened or softened weld nugget as per metal system



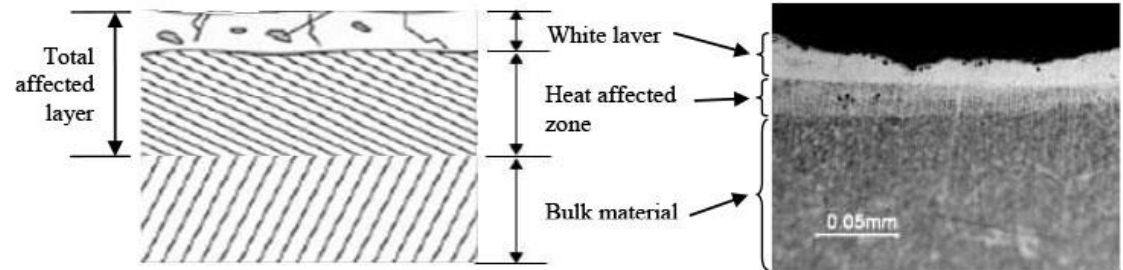
Machining

- Machining
 - Mechanical shearing: compressive residual stress at the surface so improved fatigue and tensile properties
 - Thermal: melting and ablation: re-cast layer, heat affected zone may cause abrupt change in properties as per metal system
 - Chemical: electrolysis: no residual stress so lower fatigue and tensile properties w.r.t. sheared surfaces



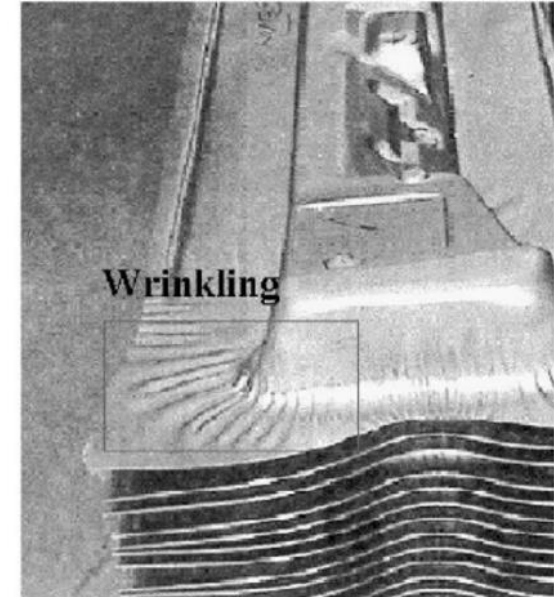
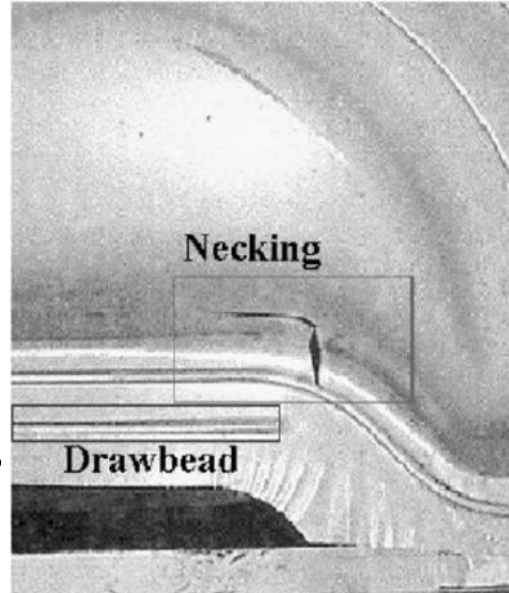
Failure of machined surfaces

- Irregular surfaces and feed marks
- Hard spot formation
- Localized softening
- Cast layer with cracks with hardening steel reduces fatigue and tensile strength



Deformation based manufacturing

- Hot/cold deformation: grain refinement / work hardening
- None-uniform deformation from surface to core
- Varying structure and mechanical properties
- Limited ductility increases cracking
- Limited localized flow increases defects laps/seams
- Banded structure and unfavorable grain flow increase notch sensitivity



Failures in deformation based processes

- Cold forming:
 - Reduced toughness
 - Increased notches sensitivity
 - Surface cracking
 - Unfavourable grain flow pattern : stronger in longitudinal direction
 - These reduce fatigue, corrosion and increase brittle fracture resistance
 - Residual stress due to localised differential deformation: anisotropic mechanical properties, localised loss of ductility
 - Increased DBTT



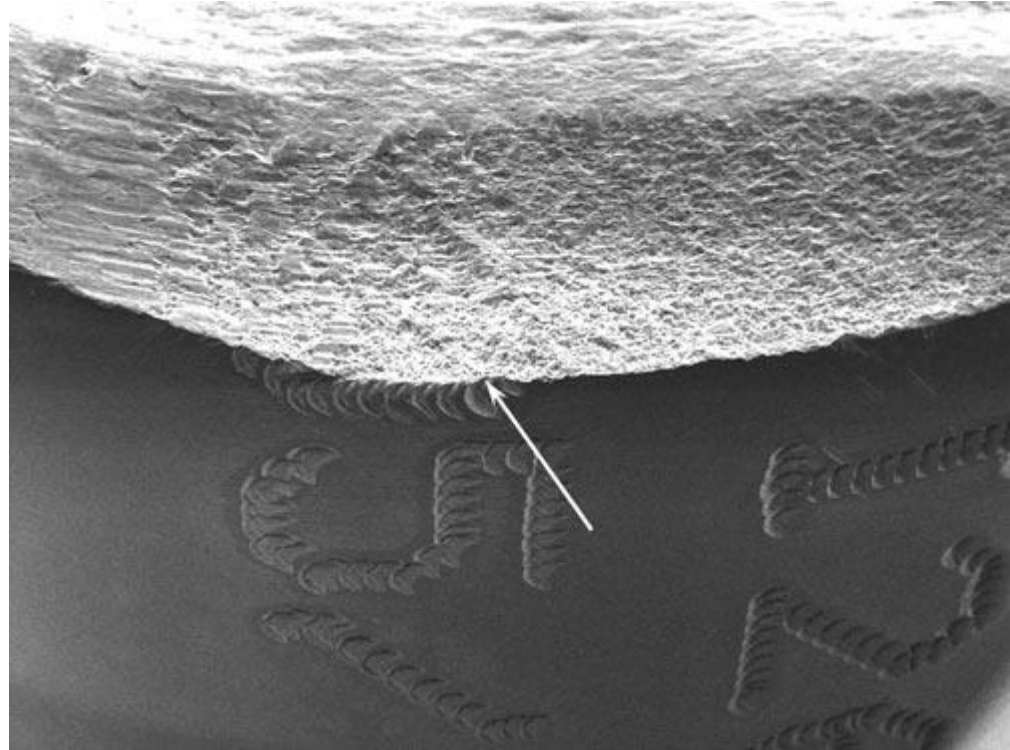
Hot forming

- Surface oxidation
- Poor dimensional control
- Poor surface finish



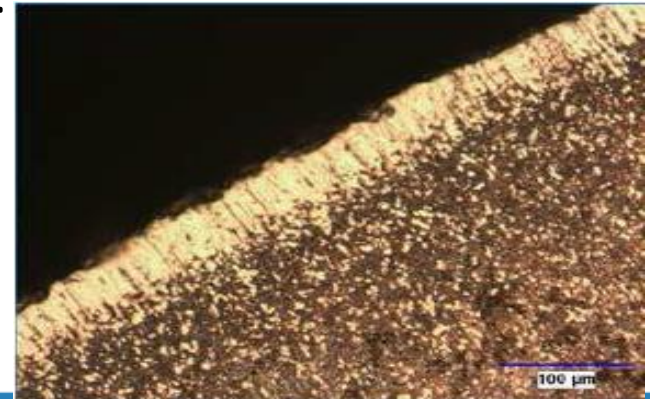
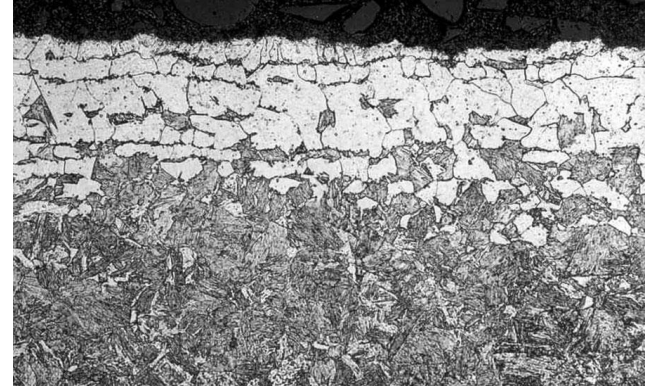
Identification marks

- Severe localized deformation
- Electro-chemical etching
- Increase cracking as these act as stress raiser especially in high stress areas



Improper heat treatment

- Overheating : partial melting, coarsening, oxidation, decarburizing
- Under/over tempering (low strength)
- Thermal shock: high temperature gradient (quench cracks)
- Unsuitable heat treatment for specific alloy: Annealing, quenching, precipitation hardening
- Loss of alloying element (decarburizing) reducing tensile and fatigue strength
- Improper control over parameters of heat treatment



Acid pickling / electroplating

- These introduce H_2 and can lead to HIC in high strength steels
- Chemical cleaning followed by coating development does not allow escaping of H_2



Reworking /repairing

- Involves partial processing of metals like welding, metal deposition
- Residual stress due to welding under restraint conditions
- These lower tensile, fatigue strength and increase cracking

