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Failure Analysis & Prevention

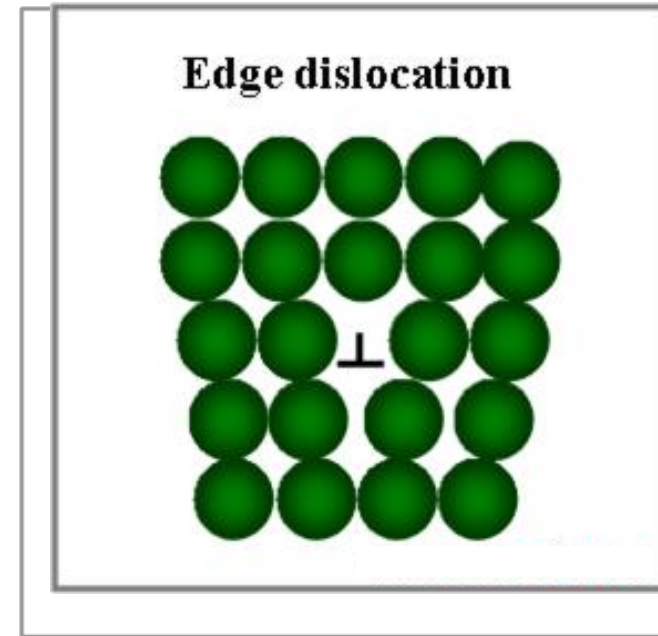
Fundamental Sources of Failure: Imperfections in Base Metal

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Base metal of Components

- Many failures originate from defects, discontinuities and imperfections present in the base metal
 - Crystallographic: vacancies, dislocations
 - Microscopic: bands, segregation, unfavourable orientation
 - Macroscopic: pores, inclusion, cracks



Imperfections in metals

- It is essentially impossible to obtain a perfect material.
- Imperfections include
 - vibrations and rotations of atoms due to high temperature
 - point defects (vacancies, interstitials, substitutional solutes),
 - linear defects (edge and screw dislocations),
 - boundary or surface defects (grain boundaries and phase boundaries, including surfaces),
 - three-dimensional defects (amorphous, pores or liquid state).



Need/importance

- Diffusion facilitated by vacancies or interstitials in metals
- Melting of metals results in large number of imperfections;
- Grain boundaries have random arrangement
- Properties such as resistivity/conductivity influenced by imperfections



Imperfections in Metals

- Not just composition but soundness of the base metal or stock metal being used for fabrication of a mechanical component is also important.
- Base metal may be not sound at micro or macroscopic levels.
- Failures are mostly contributed by microscopic discontinuities.
- Because macroscopic dis-continuities are taken care of by suitable quality assurance procedures such testing and inspection.



Microscopic dis-continuities

- These may be present in the form of
 - Dissolves unfavorable gases H_2 , N_2 , O_2 etc.
 - Inclusions of oxides, nitrides, slag, FeS etc.
 - High aspect ratio micro-constituents
 - Heterogeneity in chemical composition e.g. segregation or selective depletion of few elements
 - Varying metallurgical structures due to varying thermal cycles and deformation as per case experienced by metal during its production i.e. rolled plates, castings
 - Unfavorable morphologies: banded, laminated, plates, needle shape structures



Macroscopic features

- Ingot of base metal: cold shut, inclusion, pores, shrinkage voids, cracks (hot/cold)
- Forging: laps, seams, shrinkage, cavities, flow line pattern
- These features may be left in base metals due to improper quality control in place
 - Surface defects: Cracks, open holes, blisters, laps etc.
 - Sub-surface: Blow holes, pores, piping defects, cold shut, lack penetration etc.



Effect of imperfections

- Most of the dis-continuities acts as
 - Sources of stress concentration,
 - Reduce load carrying cross sectional area
- Most of macro-discontinuities increase maximum stress much higher than nominal stress due to both of above factors



Effect of imperfections

- While micro-discontinuities primarily lead to
 - Varying mechanical properties (localized hardening/softening)
 - Reduce tolerance to crack nucleation (for hard and brittle metals)
 - Sources of stress concentrations as notches e.g. banded structure, needles and laminates
 - Delayed cracks (due to dissolved hydrogen in steel)
 - Reduced corrosion resistance due to increased galvanic cell formation tendency like in castings owing to segregation



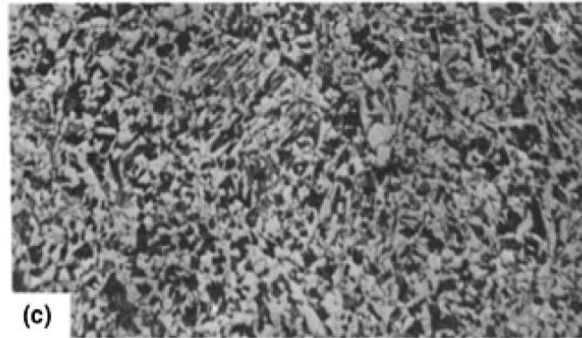
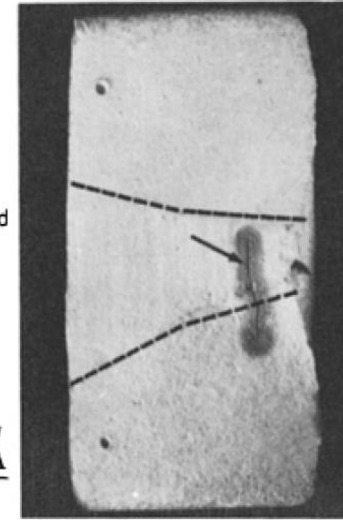
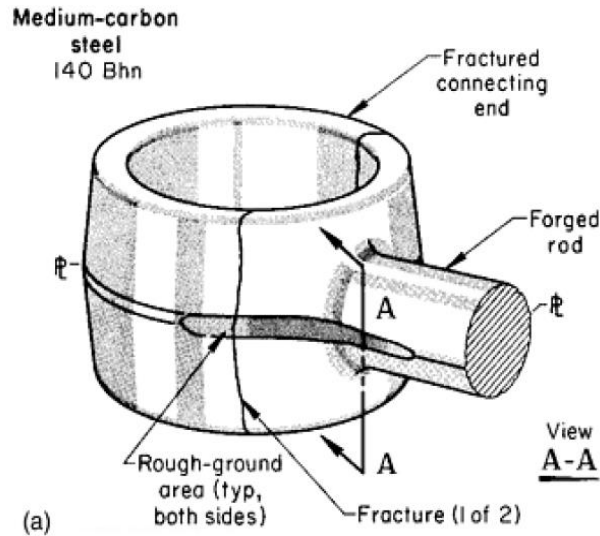
Failure of forged connecting rod

- Medium carbon steel connecting failed
- Composition with limits
- No metallurgical imperfection
- Hardness was 140 BHN instead of 160-205 BHN
- Metallography: un-used showed homo. Pearlite with equal F/P showed proper HT
- Failed one showed banded strcture near feed marks



Forging

- Fracture form transition in cross section zone
- Beach marks indicated fatigue fracture with smooth region of crack initiation
- No plastic deformation
- DPT showed fatigue cracks near fracture region with rough ground feed marks



Finding

- Notch sensitive banded structure in high stress area
- Rough ground marks stress raiser
- Low hardness
- Recommendation: control of microstructure, hardness and finish in critical areas

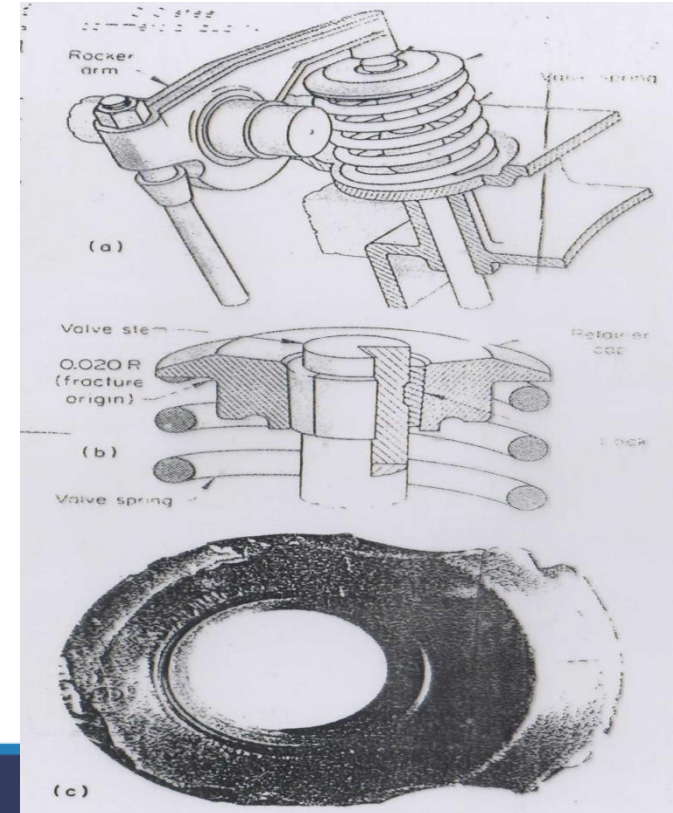
Upgrading of a Part to a new application

- A part or system had excellent performance record
- If applied to a different service condition for which it was not designed then premature failure may occur.
- Such failures suggest deficiency of design for new application
- The deficiency in design for new application may be in form of
 - Unsuitable metal of component for new application (high/low temperature, wear, corrosion, mechanical performance)
 - Heat treatment requirement (like Q & T steel temperature of T, stress relieving)
 - Size and shape requirement for carrying service load in application
 - Complex stress field becomes crucial for new stress conditions
 - Presence of stress raiser becoming critical for more severe stress condition



Upgrading of a part: Premature failure of AISI 1010 steel valve spring retainer of an engine during trial

- Retainer cap failed during 8 cylinder automobile qualification run
- Cap broke off before trial run of 200 hrs at 4100 to 4600 rpm after 26 millions of cycles
- Test simulates continuous running of engine for 200 hr at 140 miles/h
- Manufacturing: made from 16 mm cold drawn 1010 steel in annealed condition
 - Forging and then trimming
 - Case hardening: carbo-nitriding for 30 min at 843 °C and oil quenching
 - Tempering at 260 °C
 - Case depth 0.025 to 0.25 mm, HRB 86 min.

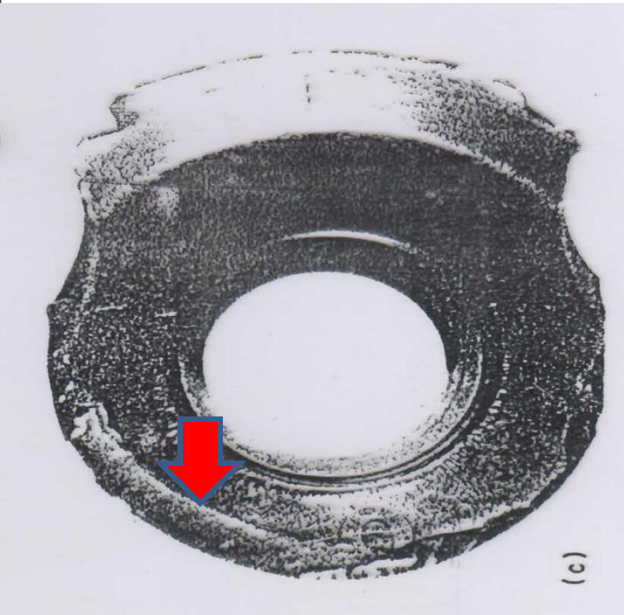


Design change case study

- Conformance to specification:
 - **chemical analysis** confirmed AISI 4340.
 - **NDT** did not revealed any internal dis-continuity
 - **Hardness** was in range of 38-40 RC
 - **Microstructure**: Normal tempered martensite as expected without any decarburization, inclusion and other abnormalities
- Conclusion:
 - Fracture by fatigue due to presence of circumferential notch at highly stressed area.
 - Notch presence was estimated to equivalent to 40% reduction in strength of spindle.
 - Variation in depth occurred due to missing hole depth info in drawing.
- Corrective action: Hole depth to keep it about 25 mm away from high stress area where change in cross section was taking place.



Deficient design: upgrading



- **Macroscopy:** flange broke off from the cap periphery
- Smooth area on fracture surface is characteristics fatigue fracture with brightness (at arrow)
- Fracture initiated at outside region of the cap along the sharp fillet
- Irregular, rugged areas correspond to final fracture
- No sign of plastic deformation or shear lips
- **Metallography:.**

Conformance

- Conformance to specification:
 - **chemical analysis** confirmed AISI 1010 (0.11 C, 0.48 Mn).
 - **Microscopy**: case depth 0.2 mm
 - **Hardness** was in range of 84 HRB slightly below than specified 86 units
 - **Microstructure**: Normal F & P structure as expected without any inclusion and other abnormalities
- Conclusion:
 - Fracture initiated and propagated by fatigue before final brittle fracture due to sharp fillet between pilot and flange
 - No significant material and manufacturing problems was found
- Corrective action: Design of cap fillet radius increased from 0.5 to 1.25 mm for better stress distribution. Increased fillet radius eased manufacturing also.

