RECENT PROBLEMS IN NIGERIAN INDUSTRIES

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The number of problems associated with Nigerian industries will increase with the development of those industries. It is expected that the Nigerian Universities should be able to solve many of these problems of its society. Indeed many cases have already been presented to and solved by the Mechanical Engineering Department of the Ahmadu Bello University, Zaria. The paper presented here illustrated some of the work dealt with during the last academic session.

CASE 1. Thermal fatigue of railway tyres.
CASE 2. Gasifier plant vibrations at Challowa Power Station, Kano.
CASE 3. Excessive wear of steel tyres and Cast Iron Brake Shoes.
CASE 4. The apparent weakness of high tensile steel bolts.
CASE 5. Failure of a Water Pump Shaft and Gear.

Case one — Thermal Fatigue

Railway wheels must not be allowed to fracture whilst in service. However fatigue does not announce itself by observable plastic deformation previous to the final sudden rupture. Hence routine inspections are necessary to see if cracks have been initiated during service.

A section of a wheel suffering from such a fatigue crack and partial rupture was delivered to the department for analysis but first let us discuss the metallurgical and stress characteristics of such wheels.

Metallurgical Factors

The composition of this wheel was 0.63% C, 0.82% Mn and 0.03% S. Such wheels are susceptible to thermal fatigue but to reduce the carbon content to increase thermal fatigue resistance will only decrease the resistance to shelling. (See Note 1)

The structure is fully pearlitic but due to the heat generated during braking, temperatures greater than the upper critical transformation temperature followed by rapid surface cooling causes a martensitic/bainite structure to form on the tread surface. This enhances the wear resistance of the wheel.

The thermal gradients developed during braking greatly affect the stress patterns produced. Fortunately one can determine the temperature gradients by noting how the structure varies from core to skin. The core has a fine grained pearlite with small amounts of proeutectoid ferrite at the grain boundaries but the layers above are the heat affected zones developed in service. First come the varying tempered zones containing ferrite + pearlite and spherodized carbides. Next comes the metal heated between the lower and upper critical transformation temperatures, whilst above this and close to the tread surface one would observe nodular pearlite, bainite and martensite. Also brake shoe metal may diffuse into the tread surface at localized hot spots should emergency braking occur, i.e. rapid high energy dissipation.

Stress Characteristics

(*a*) **Thermal Stresses**

The wheel can be considered as a number of concentric elemental fibres, each

fibre being heated to a temperature diagnosed from the above microstructure patterns. As the radius increases the temperature increases and the outer fibres tend to circumferentially expand more than the adjacent re-straining fibre beneath. Induced compressive stresses therefore result in the outer layers which cause plastic deformation. When the metal cools down these outer fibres shrink below their original length by an amount approximately equal to the permanent set initially suffered when under compression. Again the inside fibres act as restraints and so induce a hoop tensile stress in the outer fibres. This cyclic heating induced by braking, thereby causes a cyclic stress variation and cracking can occur in only one or a few thermal cycles.

(b) **Stresses Associated with Microstructural Changes**

If there is a carbon content increase due to diffusion of brake shoe metal near the surface, a decrease in volumetric expansion relative to the parent structure results as austenite transforms to pearlite. The carbon rich outer layers therefore develop tensile stresses. (See Note 2)

(*c*) **Initial Residual Stresses**

To produce a residual compressive stress in the rim to oppose the tensile stresses developed in service a rim quench is carried out as a standard manufacturing operation.

(d) **Other Considerations**

(*i*) **The Elevated Temperature Strength**

At high Temperature the fatigue resistance and other strength properties of the metal can be drastically reduced.

(*ii*) **Dynamic Stresses**

During each revolution of a wheel the vertical compressive loading causes the fibres to undergo 2 stress reversal cycles.

(*iii*) Other effects which influence the stress patterns are stress relaxations at elevated temperatures, the Baushinger effect, lateral thrust, and rolling contact stresses.

The Failed Specimen

Observations illustrated that microstructural changes occurred to a depth of 0.075 in.

From repeated braking operations the residual pre-service compressive stress in the rim was changed by thermal cycles into one of tension. Cyclic stress variations caused a fatigue crack to be initiated and propagated at the junction of the tread and vertical faces, see sketches 1 and 2, where there were indications of flaked out metal and cracks.

Sketch 1 shows the failure zone of the wheel, and sketch 2 gives details of the radial thermal fatigue crack and surrounds.

It was during a cooling cycle and the development of rim tensile stresses that the final explosive fracture took place but fortunately it did not penetrate beyond the web. The final fracture was itself precipitated by the stress concentrations

around the fatigue crack root.

Excessive heating and thermal damage was due in this case to prolonged drag braking and over-hanging brake shoes evidenced by the flaked out material and since this particular wheel was extra thick, heat transfer from the rim rapidly quenched the locally heated tread area thereby aggravating thermal cracking.

A greater chamfer at the vertical face tread corner would help reduce brake shoe contact at this critical point but the main remedy is to be found in better braking procedure and early removal of high wear rate brake shoes.

Notes

1. Shelling is the flaking off of the tread surface when fatigue cracks are produced by rolling contact stresses.
2. Again the tempering of martensite also induces internal tensile stresses. However these type of cracks called "Thermal checks" do not propagate but are worn away. These type of cracks however can be a possible source of fatigue cracks.

Case Two — Structural Vibrations

A new plant was installed in an existing building. This plant had its own reinforced concrete supporting structure so in reality there was an inner structure and a surrounding one.

The new plant was a gas turbine driven alternator and the hot gases were supplied from free piston engine gasifiers. Air intakes to the gasifiers were located on the ground floor whilst the free piston engines were mounted on the first floor. Gasifier outlets pipes were carried by overhead arches above the gasifiers. Large energy pulses generated by the periodic gas outlet charges, vibrated the structures mainly in the direction of the gas piping axis.

The problem was in three parts:

(*i*) How critical were the vibrations to the structures.
(*ii*) How were the pulses transmitted to all parts of the buildings.
(*iii*) Could the vibration be stopped or minimised.

Frequency and amplitude vibrations were measured by allowing the free end of a probe to carry a magnet which oscillated inside a coil. The other end of the probe could be rigidly attached to any point of the structure. A voltage signal was thereby induced which was monitored into an oscilloscope.

The vibrations, whilst alarming, were not serious as far as the inner structure was concerned. Failures of supports would have occurred as a result of incorrect design or faulty workmanship long before our inspection.

However the old building structure vibration was more serious. Large cracks in the concrete panels had developed and amplitudes of 0.070 inches indicated that the panels could possibly disintegrate. The control room some 60 yards away from the gasifiers, vibrated so much as to render useless a mechanical automatic voltage regulator.

By noting the mode of vibration of the gasifier floor and gas outlet piping it was apparent that the piping anchor blocks were transmitting energy principally

via the foundations.

Frequencies of each gasifier, the gas pulses, the anchor blocks and the old structure were all in the order of 10 cycles per second. Furthermore, calculation showed this frequency to be near the natural frequency of the old structure.

Recommendations for minimising the vibrations included the following:

(*i*) The gasifiers should be out of phase controlled to eliminate the fundamental frequency.

(*ii*) Certain girder work attachments from the new to the old structure should be removed as these acted as exciters.

(*iii*) The concrete panels in the old structure should be removed and steel work added to stiffen the structure, i.e. increase its natural frequency.

Case Three — Wear Problems

(*a*) **Railroad Wheels**

When railroad wheels have done approximately a half million miles, they need replacing. It is economical to retread the wheels by fitting on steel tyres. Such tyres were previously fitted in U.K. but industrial developments gave encouragement for their fitting here in Nigeria. When fitting, it is necessary to expand the tyre until it can be just dropped over the wheel, but a controlled heat treatment procedure is essential. The desired structure of the tyre should be pearlitic and due to repeated thermal cycles at the tread surface during service a thin martensitic structure should result giving good wear charactersitics. However, the Nigerian fitted tyres were not giving one tenth the expected wear life, so sections of new tyres, previous to being put into service, were delivered to our department for analysis. Microstructural examination immediately gave the answer — decarburization of the pearlite leaving a ferrite skin.

The ferrite skin tread, if placed in service, will have two complimentary deficiencies due to lack of carbon in that a martensitic skin will not form and the ferrite skin will wear rapidly. Another deficiency as observed in a previously supplied badly worn tyre was that the faulty heat treatment left radial cracks and fissures of scale in the skin and the cold work due to the rolling action of the wheel had bent over the cracks in a circumferential direction. Such cracks facilitate pealing of the tread skin. The remedy here is better control of the heating of tyres so as not to allow excessive decarburization or other structural alterations, over-heating or over-expanding.

With more experience an engineer should be able to tell the state of the tyre during heat treatment, as well as to state the nature of the skin and amount of post machining necessary to remove all traces of the ferrite skin.

Some results

(*i*) Chemical Composition of the Tyre:
C 0.74; Si 0.3; Mn 0.64; Ni 0.10; Mo 0.18

(*ii*) Photomicrographs:
These are kept in the author's files.
Etchant 2% Nital.

(*b*) **Railroad Brake Shoes**

The Cast Iron brake shoes now made in Nigeria had a very limited life with

consequent frequent renewals and loss of service time. Furthermore, rapid wear of these shoes would lead to overhanging brake problems as already mentioned in Case One.

Upon examination the fault and remedy was found to be in the casting procedure. There was no great chemical composition variations between a bad and good shoe but a good wear resistant shoe should have its mould chilled and an expanded metal framework in the mould core to act as an internal chill and also to add some toughness to the chilled iron. Such a shoe of white chilled cast iron would give excellent wearing properties having hardness values of approximately 450 — 500 V.P.N.

However, the faulty shoe was not a chilled casting and its structure was of an ordinary grey phosphoric cast iron having a V.P.N. of 255. Embedded in the pearlite matrix were medium sized flakes of free graphite which could diffuse into the Wheel tread surface so leading to other undesirable problems.

Case Four — High Tensile Steel Bolts

One of the disadvantages of a constant mesh or helical gear is that it transmits an axial thrust. To keep the gear in position a retaining washer is usually fixed to the gear shaft by high tensile steel bolts.

However, in this case, the thrust developed was sufficient to break the bolts. A sample bolt was delivered to the department for our examination.

An examination of the microstructure revealed two important points.

1. A 0.050 in. ferrite skin contoured the thread profile and this skin contained many cracks. The bolt core structure was sorbitic pearlite.
2. Because the ferrite was contoured to the profile it was obvious that a post machining heat treatment was given to the bolt.

In other words, the alloy steel bolt thread was first rolled and then heat treated to achieve a sorbitic pearlite structure. Whilst this structure has the desired strength however, the heat treatment was faulty since decarburization took place and a cracked ferrite skin resulted. Such cracks are easily propogated especially at stress concentrations at the thread and so the bolts were apparently weak.

Some results

(*a*) Hardness variations:
Bolt core 286 VPN
Bolt skin 229 VPN

(*b*) Tensile properties of core:

Yield stress ton/in^2	43
U.T.S.	56
% elongation	16
% reducation of area	52

(*c*) Chemical Compositions:
C 0.38; Mn 0.78; Ni 0.16; Cr 0.10;
Si 0.33; Sn 0.38; Cu 0.18;
Co 0.03 and Mo, W, V, Ti, A1 C 0.01

(d) Photomicrographs:
These are kept in the author's files.
Etchant 2% Nital.

Case Five — Shaft & Gear Failure.

This problem was in two sections but one was complimentary to the second. A bevel gear had worn rapidly and the shaft on which the gear was located had ultimately fractured.

A chemical analysis showed the gear to be a 1% Nickel steel with a V.P.N. of 203.

The general structure was of accicular pearlite and ferrite and there was no evidence of even a shallow hardening on the teeth and whilst the gear contained no excessive or abnormal non metallic inclusions the gear was obviously in an untreated and unsatisfactory condition.

Experiment on a small section removed from the gear showed that by an oil quench and tempering treatment the hardness could be increased 42% and a much finer grain structure obtained.

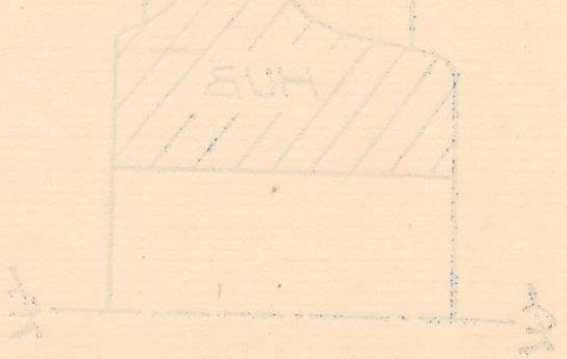
The shaft was next analysed and here the 13% chromium steel with a plain carbon steel clad was found to contain rather excessive non-metallic inclusions of a non-plastic nature which would readily act as severe stress raisers so rendering the material sensitive to crack initiation.

The shaft failed initially at the root of a thread due to:-

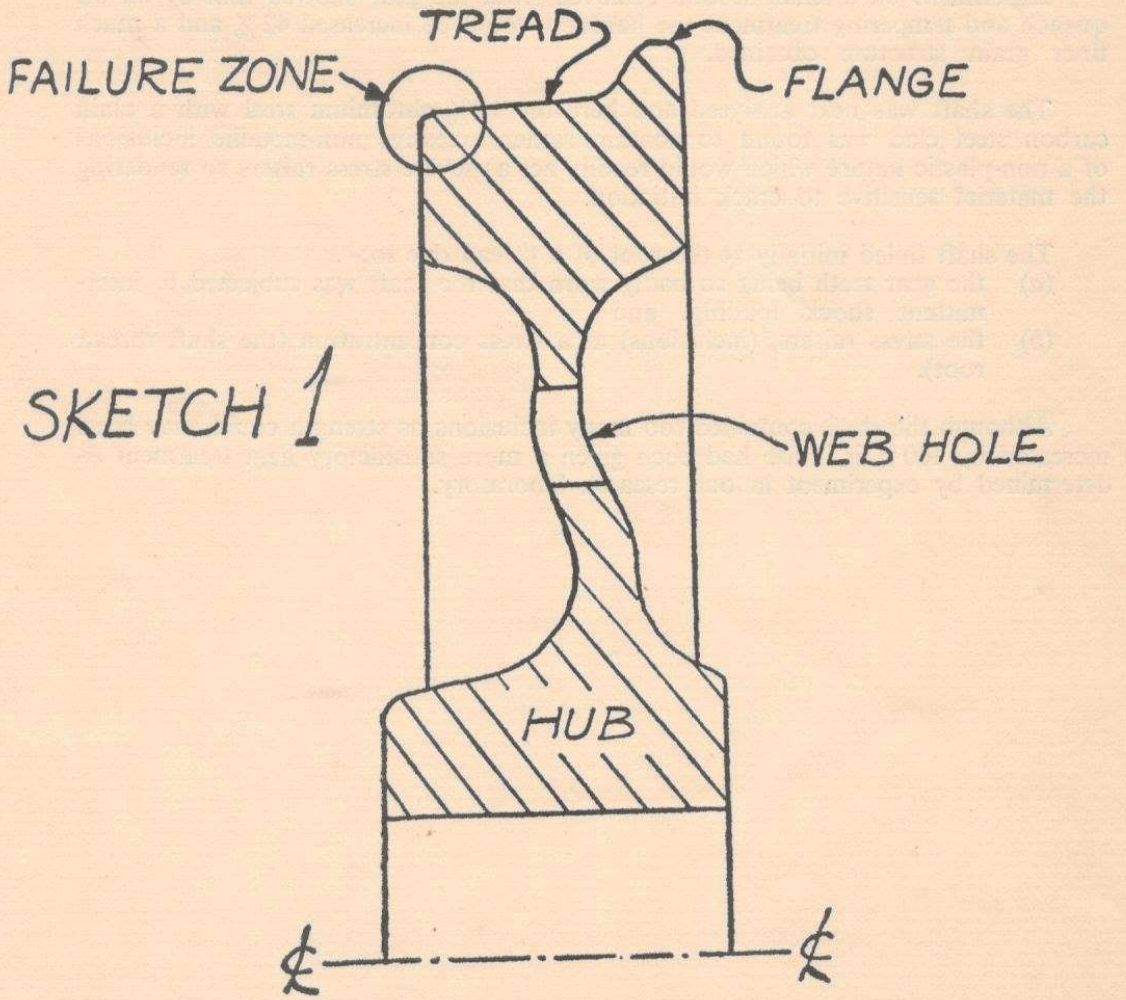
(*a*) the gear teeth being so badly worn that the shaft was subjected to intermittent shock loading, and

(*b*) the stress raisers, (inclusions) at a stress concentration (the shaft thread root).

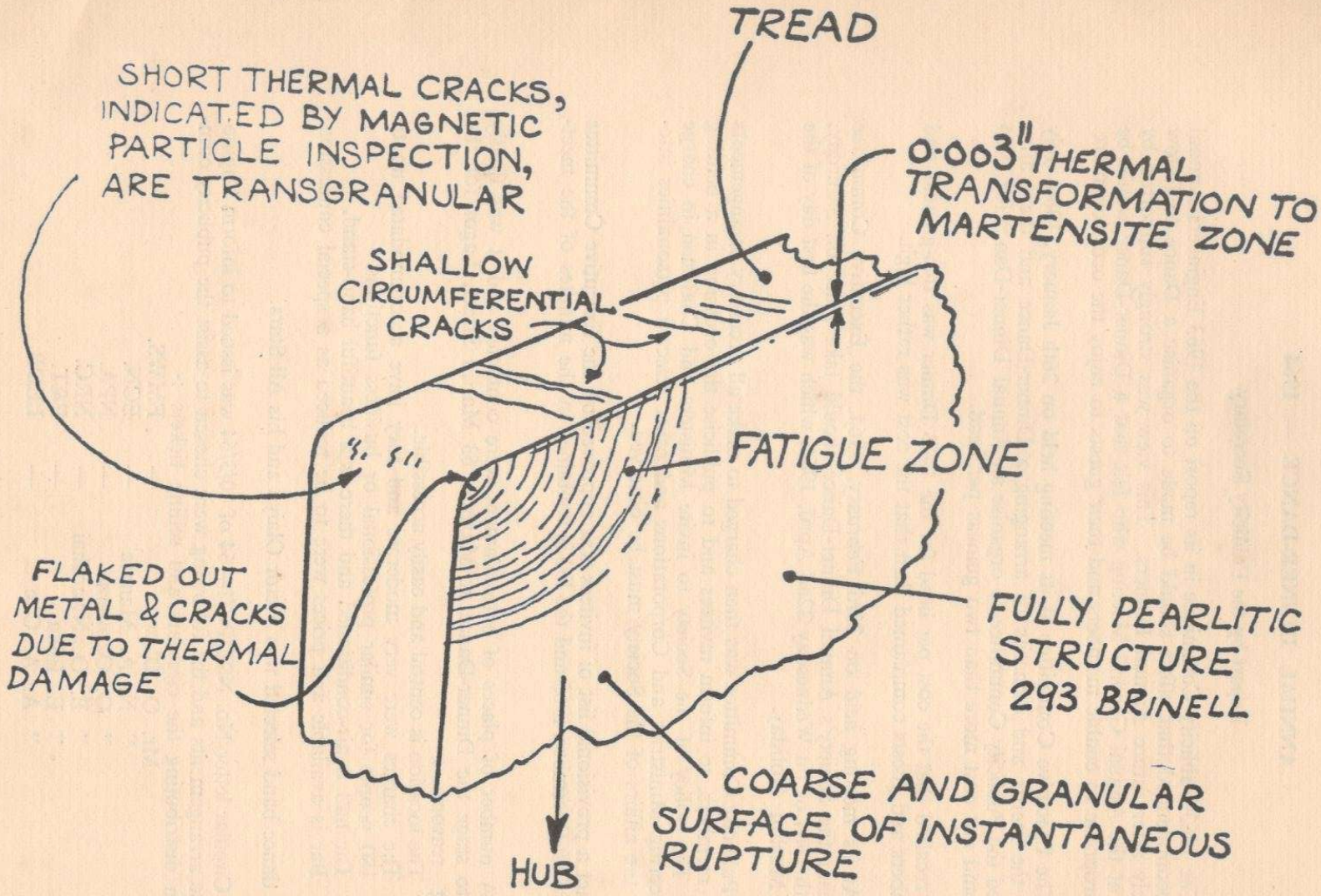
Although the shaft contained too many inclusions its strength could have been increased by 100% if it too had been given a more satisfactory heat treatment as determined by experiment in our research laboratory.



TYPICAL SOLID FORGED & ROLLED STEEL WHEEL SECTION



SKETCH 1



SKETCH 2, FAILURE ZONE