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ANALYSES OF FRACTURES THAT HAVE CAUSED TRAFFIC ACCIDENTS

SUMMARY

The paper analyses some fractures of vehicle components which have caused traffic accidents. The methods of analysing the cause of fracture have been described, as well as the main types of fractures. The first analysed cause of a fracture is the excessively rough machine finish which leaves cracks (stress concentrators), the starting points of crack propagation. The second cause is unprofessionally performed welding which later in service causes fracture at the weld. The third cause is the too high content of carbon in the material of the railway vehicle wheel rim. During braking, the higher content of carbon caused formation of excessively hard (and brittle) martensite in the surface layer of the rim.

1. INTRODUCTION

Traffic accidents are in the majority of cases caused by "carelessness" of the very persons involved in the accidents. However, quite a significant number of traffic accidents, which apart from material damage end with fatalities, are caused by fractures. Investigating the cause of a fracture in such accidents is very important both in order to establish the guilt and in order to prevent such fractures in the future. For example, it is important to determine whether the fracture, visible after the accident, was caused by the accident itself, or whether it had occurred directly prior to accident thus causing it to happen.

Vehicle manufacturers produce and check all the vital parts according to the internationally set standards, so that accidents caused by fractures of these parts are practically impossible. However, over many years of service the material of the vehicles is subjected to both "ageing" process, as well as various impacts, overloads, etc. thus causing the vital parts to lose their initial properties. Apart from this, various non-professional repairs, replacements of obsolete parts by parts of "dubious" quality, low-quality welding, etc. can be the cause of fractures.

This paper analyses the fractures which have caused accidents.

The basic reason of a fracture is excessive stress. Such stress is usually caused by the interaction of various factors such as:

1) Load
   - type (static, dynamic)
   - stress distribution per cross sections
   - residual stresses

2) Material
   - chemical composition
   - mechanical properties
   - micro-structure
   - non-metal inclusions

3) Elements forms
   - dimensional requirements
   - forming regarding reduction of stress concentrators
   - residual cracks from machining

4)Environment
   - atmospheric agents
   - corrosive environment
   - temperature (in service)

2. METHODS OF ANALYSING THE CAUSE OF FRACTURE

After the fracture has occurred, it is important to collect carefully the fractured parts and to take them for analysis. The fractured surfaces usually need to be cleaned first so as to remove the protective coating, corrosive layer, and other deposits. Before cleaning, the layers covering the fractured surfaces need to be analysed because they might offer valuable information regarding the cause of the fracture. Cleaning can be done by dry air jet, inorganic solvent, mild acid, or alkaline solution, and ultrasonic cleaning. It is often useful to take a plastic reproduction (replica) of the fractured surface, which does not damage the specimen itself. For electronic microscope analyses, namely, the specimens need to be of small dimensions, so that the fractured part often has to be cut which can cause further damage of the fractured surface.

It is very useful during analyses to have an equal undamaged part, as well.

The analysis of the cause of the fracture begins by visual inspection which can, in some cases, already determine the cause, then confirmed by further analyses. The visual inspection determines also those spots which are to be analysed later in detail. Further inspection can be carried out by optical stereo-microscope (magnification up to 50 times), optical microscope (magnification 50-1000 times), electronic scanning - SEM (magnifications 5 - 240 000 times) and transmission - TEM (magnification 210 - 300 000 times) microscopes. It is important to know the chemical composition of the analysed part, its mechanical properties, microstructure, and possibly also micro-hardness.[1]

3. BASIC TYPES OF FRACTURES

Although fracture is caused by interaction of a number of various factors, fractures could still be classified into several basic types:

1. ductile fracture
2. brittle fracture
3. fatigue failure.

1. Ductile fracture

The basic characteristic of a ductile fracture is the rupture of material accompanied by plastic deformation with a significant energy expenditure. The fractured surface has a fibre appearance.

Ductile fracture due to tensile stress occurs perpendicular to the direction of the load, and due to shear stress at an angle of 45 degrees from the surface towards the core.[2]

2. Brittle fracture

Brittle fracture is characterised by rapid crack propagation without any major plastic deformation, and with a significantly lower energy expenditure than with ductile fracture. Brittle fracture has a granular appearance, and the fractured surface is mainly perpendicular to the direction of the stress.

The propagation of the brittle fracture can be inter-granular or trans-granular. Inter-granular crack propagation causes granular fractured surfaces, whereas trans-granular fracture propagates along parallel crystallographic planes, thus making the layered fractured surface visible.

3. Fatigue failure

Fracture due to fatigue of the material is caused by long-lasting dynamic stress at a load much lower than the allowed. The crack occurs at the point of stress concentrator and over time it propagates slowly, and reduces the cross section surface, thus increasing the stress within the part at equal load.

On the fractured surface, a very smooth part caused by long-term fracture can be differentiated from the rough surface of the current brittle fracture.[2]

4. EXAMPLES OF FRACTURES

4.1. TESTING OF DYNAMIC ENDURANCE

Dynamic endurance is an important indicator of the behaviour of the part in service at variable loads. This is the maximum dynamic stress which a material can endure at a practically infinite number of changes without failing.

Dynamic endurance is usually tested by pulsars and determined according to the Wöhler's curve. Such testing is valid only for the exact part (of certain dimensions, shape, machining condition, material, micro-structure condition, and type of dynamic load). The testing is carried out always on three specimens, such that the first testing begins by stress greater than the expected value for the dynamic endurance. After fracture of the first three specimens, the next three are tested at a lower load, thus increasing the number of variations. Testing is continued up to the stress at which the material can endure practically an infinite number of variations without failing (Figure 1).[3]

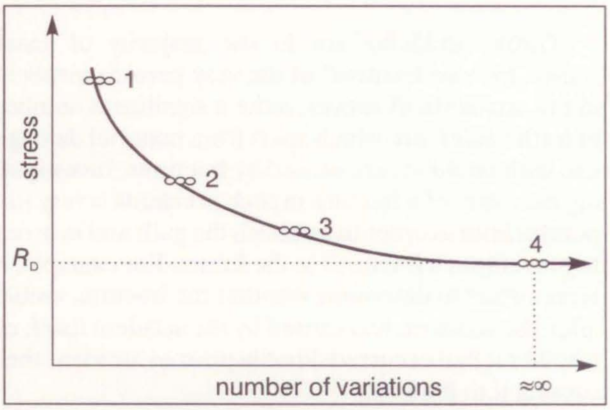

Figure 1 - Determining of dynamic endurance using Wöhler's curve

Source: Perše, S.: Osnove strojarstva I (Eng: Fundamentals of Mechanical Engineering), Fakultet prometnih znanosti, Zagreb, 1993

where:

1 – fracture of the first three specimens

2 – fracture of the next three specimens

3 – fracture of the following three specimens

4 – no fracture occurred

R_D – dynamic endurance

The example of testing the dynamic endurance in practice is the testing of the third self-rotating shaft in the FAP vehicle.[4] The shaft is loaded torsionally. The value of the lower and upper limit force (F_d=50 kN; F_g=100 kN), and load frequency (7 variations per second) have been adequate to the maximum loading in practice. The shaft fractured after 856 000 variations (the limit for variations in steel is about 6 million)[3], from two sides, at the point of reduction in shaft thickness, thus providing an insufficient radius of curvature and as such acting as the stress concentrator. In order to increase the dynamic endurance of this shaft, the radius of curvature needs to be increased.

4.2. ANALYSING THE CAUSES OF FRACTURES IN TRAFFIC

4.2.1. Analysis of the 441 electric locomotive shaft fracture [5]

The fracture occurred at the shaft groove. It could already be determined by visual inspection that the fatigue of the material was the cause of the fracture. Smooth fractured surface indicates the steady, gradual propagation of the crack, and the surface of the current fracture is relatively small. Since the radius of curvature of the groove is fairly big, it cannot be considered as the stress concentrator causing the beginning of the fracture. The groove showed traces of cutting due to machining, and the high stress concentration at those points caused the occurrence of cracks. Such stress concentrators can be eliminated by fine machining following the rough one.

4.2.2. Expert opinion on the shaft fracture of the manually operated vehicle 58-61-Zg [6]

The visual inspection of the fractured surfaces showed that the fracture on the right bond occurred along the whole welding line, and at the left bond it enters only a little the base material.

It has been found that the root of the weld has been insufficiently welded, which is only 1/3 of the thickness of the base material. Such a weld is especially dangerous in dynamic loading due to notch impact at the weld root. The cause of the fracture is the low-quality welding procedure. Such a welded joint could cause fracture even in normal operating conditions. The dynamic endurance of the shaft can be increased by such a welding procedure which would increase the welding properties of the weld root.

4.2.3. Testing the material and analysis of the cause of the railway vehicle wheel rim fracture [7]

Visual inspection of the outer area - area of contact has discovered cracks, and at some points also dark blue spots which indicates heating due to braking friction. The thickness of the fractured rim was about 42 mm, and according to documentation the new rim has a thickness of 79 mm. Chemical analysis showed that the chemical composition matched the regulations, except for the portion of carbon which amounted to 0.53-0.57%C, whereas it should have been lower than 0.48 %C. The mechanical properties were in accordance with the rules, and the microstructure of the inner part of the rim was mostly pearlitic with a small portion of ferrite which corresponds to normalised condition.

Cracks go as far as 2 mm into the depth. In the thin outer layer of about 80 μm thickness, the microstructure is martensitic, and the measured microhardness amounts to over 1000 $HV_{0.2}$. This martensite was caused by sudden heating of the surface due to friction, and by very rapid heat transfer into the interior of the rim.

The hard surface martensitic layer has caused the occurrence of cracks and "scaling". Such zones occurred during service much earlier than the rim fracture. The reduction in the carbon portion in the rim material would reduce the hardness of the martensite due to friction, and the possible occurrence of cracks and "scaling" of material would be of slower progress.

4.2.4. Analysis of the steering wheel overgear shaft fracture in the passenger car Citroën Dyana [8]

The part of the tube of the steering wheel shaft was analysed with the fractured toothed overgear shaft. The tube was plastically deformed due to vehicle impact. The edge of the fractured surface of the overgear shaft to the depth of about 1.5 mm corroded more than the rest of the fractured surface. It could also be seen that the fracture occurred along the less deep groove made by the lathe. The micro-structure of the shaft core is ferrite-pearlitic, and along the edge martensitic, indicating that heat treatment of surface hardening had been performed (proved by microhardness measurement). The analysed fracture occurred on two occasions - the first one much earlier than the final fracture (the stronger corroded fractured surface along the edge). The fracture could have been caused by the shallow groove due to turning operation. The fracture of the overgear shaft is the cause and not the consequence of the vehicle traffic accident.

4.2.5. Analysis of the tank-lorry rear platform parts fracture [9]

The part of the rear platform shaft, two parts of the fractured bolt and toe-in link of the rear platform were analysed. The shaft fractured suddenly at the weld without plastic deformation and without any signs of fatigue. The bolt broke instantly with plastic deformation. The toe-in link fracture was extremely corroded, leading to a conclusion that the fracture occurred much earlier than other fractures (of the shaft and of the bolt).

The shaft micro-structure is ferrite-pearlitic. The shaft is normalised. The micro-structure in the heat affected zone between the weld towards the basic material is martensitic (confirmed by the micro-hardness test, which in the heat affected zone amounted even to more than 550 $HV_{0,2}$. The bolt micro-structure is normalised, and of toe-in link ferrite, of Widmannstäten type. The chemical composition of the shaft matches the improved steel Č.2130, and that of the bolt also the improved steel Č.1530.

The brittle micro-structure of the toe-in link material caused by welding (Widmannstäten) is inadequate from the aspect of mechanical resistance of the vehicle element subjected to extreme dynamic loads. Also, the bolt and shaft material is not improved, and during welding on the shaft, brittle martensite formed in the heat affected zone of the weld. The fracture started at the beginning or at the end of the welded joint. The shaft and toe-in link welding procedures were performed extremely non-professionally with damaging effects to the mechanical resistance of the shaft bearing surfaces themselves. The bolt fracture was caused by vehicle overturning. Such failures due to the lack of heat treatment, and even more due to inadequately performed welding are reason enough to cause fracture even in normal service conditions.

5. CONCLUSION

In these several examples of fractures in traffic, it is obvious that the cause of traffic accident does not always have to be "human factor". Fractures described in this paper have been caused by the production technology of the vehicle parts.

One of the causes is the lacking fine machining in lathe operations. Also, the relatively shallow scratches are the stress concentrators that in dynamically loaded parts cause cracks which propagate with time (fatigue failure of the electric locomotive shaft, and the fracture of the passenger car steering wheel overgear shaft). This cause of fracture can be prevented by fine finish in machining which will eliminate all the rough scratches left over from the previous treatment.

Another reason is totally unprofessionally performed welding. In the shaft fracture of the manually operated vehicle insufficient welding of the weld base could be noticed. Sudden change of micro-structure, and thus also of material properties can also be the stress concentrator in dynamic loading conditions. The analysis of the rear platform parts fracture in a tank-lorry showed that the shafts and the bolt were not sufficiently improved, and the welding of the toe-in link and shaft was done unprofessionally (the formation of the soft and brittle Widmannstäten structure in the toe-in link material and martensite in the shaft).

The third mentioned cause is the fracture of the railway vehicle wheel rim. Interesting to note is the formation of the hard and brittle martensite on the outer rim edge. The martensite formed by braking friction, and caused further occurrence of cracks and "scaling" of the outer layer, as well as thinning of the rim. Selecting the wheel rim material with less carbon content would reduce the hardness of the formed martensite, thus reducing the propagation of the surface "scaling". Since, however, this "scaling" cannot be eliminated the used wheel rim should be replaced more often by a new one.

SAŽETAK

ANALIZE LOMOVA KOJI SU UZROKOVALI PROMETNE NEZGODE

U radu su analizirani neki lomovi dijelova vozila koji su uzrokovali prometnu nezgodu. Opisane su metode ispitivanja uzroka loma,, kao i osnovni tipovi lomova. Prvi analizirani uzrok loma je pregruba završna strojna obrada iza koje ostaju risevi (koncentratori naprezanja) na mjestima kojih počinje širenje pukotine. Drugi uzrok je nestručno proveden postupak zavarivanja koji je kasnije u eksploataciji uzrokovao lom na mjestu zavara. Treći uzrok je prevelik udio ugljika u materijalu obruča kotača željezničkog vozila. Viši udio ugljika uzrokovao je, prilikom kočenja vozila, nastanak pretvrdog (i krhkog) martenzita u površinskom sloju obruča.

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