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DAMAGE MECHANISMS OF HEAVY LOAD WHEELS IN LOGISTIC APPLICATIONS

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1. Introduction

Nowadays the logistic jobs need heavier and more powerful floor conveyor systems and industrial trucks with high-performance wheels that can tolerate a higher dynamic load under extensive weight increase. Compared to wheels of solid metal wheels with an elastic solid bonded tyre of synthetic material have the benefit that they wear little that they affect the opposite face little that they are low-noise that they absorb the impacts by an intern attenuation that their friction tests are good, and that they are low-cost. Due to their better mechanic features compared to rubber products massive polyeruthane has become accepted as the material for the massive tyre of heavy load wheels in many logistic systems.
Standstill period in logistic systems due to unexpected malfunction of those wheels can cause great economic damage. To guarantee the most potential availability of those systems different damage processes of heavy load wheels and their use must be analysed so that the conditions can be improved. In the following the mechanisms are recorded which can lead to a failure of the heavy load wheel.

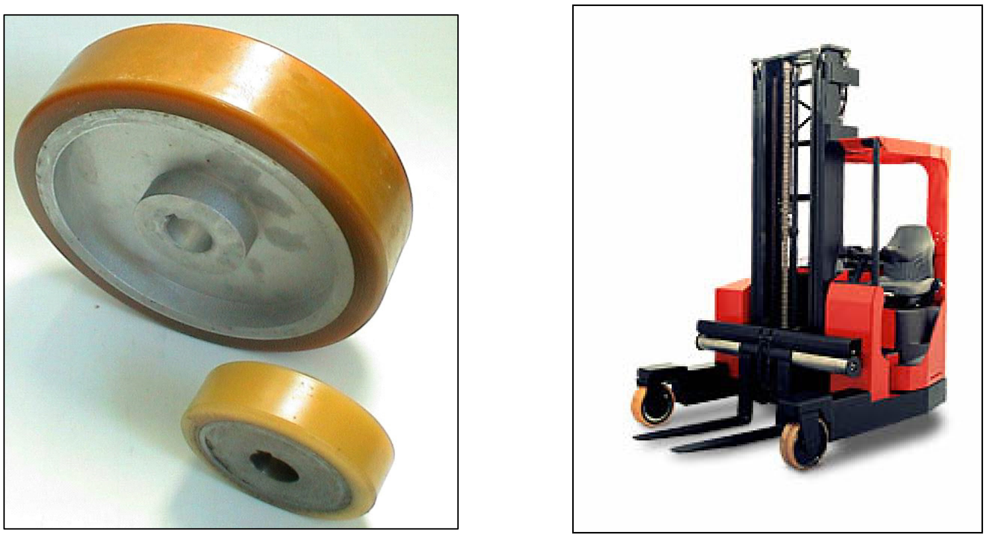

Figure 1. Heavy load wheels diameter 200 and 100 mm, example of use

2. Types of damages of heavy load wheels

Depending on the kind of load and the external boundary conditions heavy load wheels with solid polyeruthane tyre can fail through abrasive wear, thermal failure, or tread delamination (Figure 2).

Figure 2. Different failure forms: Abrasive wear, thermal failure, tread delamination

2.1 Thermal failure

Especially for rapid running wheels of plastic the temperature of the wheel body affects the acceptable mechanic load. High dynamic loads caused by high deformation and speed lead to a heat build-up in the middle of the tyre as a result of material damping of the visco-elastic elastomer face. Since plastics are bad heat conductors the heat cannot dissipate quickly enough due to the thermic insulation of the PU. As a result a heat accumulation appears in the roll-tread. The material melts inside of the wheel and liquid leaks out of the flanks (Figure 4).

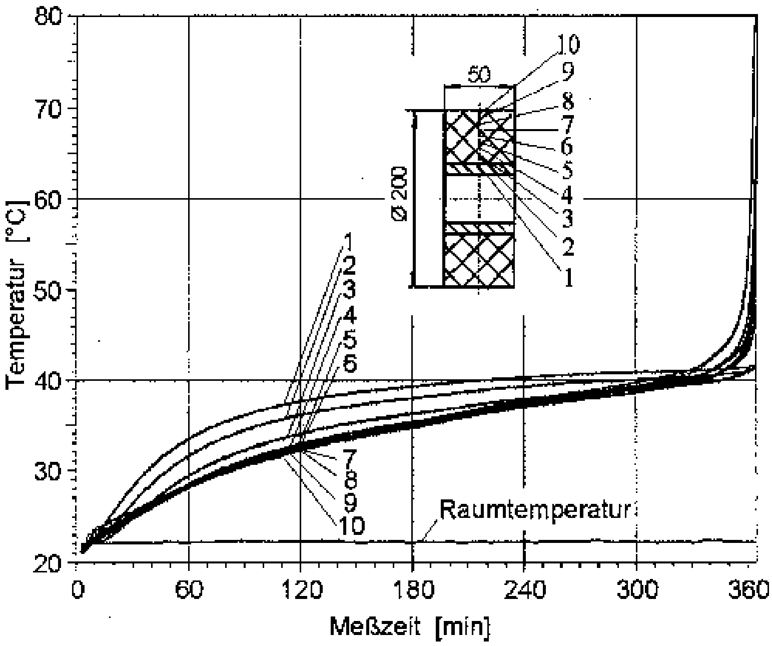

Figure 3. metered temperature allocation in the wheel body (Qiao)

To dimension a wheel the load should be adapted according to a rule of thump:

$$F_{\mathrm{N,max}} = 800\ \mathrm{N} \cdot \frac{wheel\,width}{10\ \mathrm{mm}} \cdot \frac{wheel\,diameter}{100\ \mathrm{mm}} \qquad (1)$$

This formula applies to wheels with a tread-hardness of 92 shores-A and has to be adapted to lower tread-hardnesses. In use of the maximum load capacity the speed should be less than 10 km/h.

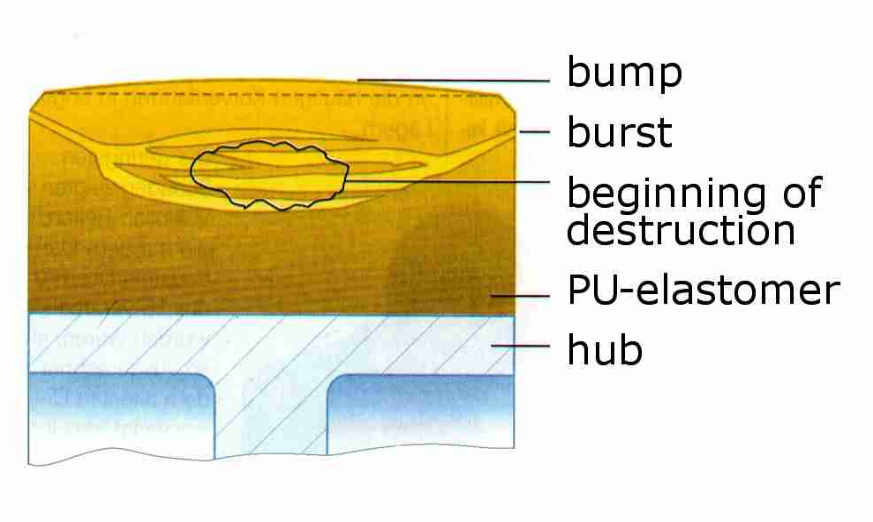

Figure 4. damage picture of a thermal overloaded tread (Bayer)

2.2 Abrasive wear

Currently finished examinations have shown new conclusions about the abrasive behaviour under real use conditions. Especially the abrasion under action of intermediate material in the contact area between the tread and the contact surface, on which the wheel rolls off, is analysed in the project about abrasion behaviour of powered synthetic coated wheels for the friction gear actuation piece goods handling which is sponsored by the “Bundesvereinigung Logistik” (BVL). It is now possible to have access to findings on the impact of boundary conditions for the choice of material and the dimensioning of drive wheels.
As to the intermediate material an abrasive effect appeared at the material which affects especially the crack dispersion. On the other hand it showed a chemical effect to the polymer material of the heavy load wheel in particularly at liquid materials.
For the analysis of these impacts a testing system is developed. This helps to experiment the abrasive behaviour of heavy load wheels with polymer tread under the influence of intermediate materials with a highly realistic copy of the loading collective. The abrasive behaviour was acquired by the loss in weight of the samples within the testing period of 24 hours under rated load. Additionally the surface damage of the wheel is viewed and assessed both macroscopically and microscopically.
For feeding the intermediate material into the contact area compressed air is used both for liquid and solid materials. The contact area is perpendicularly arranged in order to obtain a certain self cleaning-mechanism. The supply of the intermediate material is adjusted in such a way that in each case one kg solid and one litre of liquid is fed into the contact zone per hour. A permanent presence of intermediate material between test wheel and counter wheel is ensured during the tests. The regarded intermediate material are further described.

- Normal glass sand with an average grain size of 0.5 mm, 1 mm and 3 mm
- Metal chips of cast irons. These are relatively small (about 3 mm) and sharp-edged
- Corundum with a grain size of 0.2 mm
- Stone chippings with an average grain size of 3 mm
- Normal tap water with all its contained ingredients
- Cuttingoil “Kutwell® BR40” of the company ESSO. The mixing proportion in water is 6%
- Engine oil 15W/40
- Water with a saturated salt solution

It has turned out that the abrasion reaches the highest rates under the presence of water. The combination of chemical corrosion and dynamic load explains the high abrasion. The chemical corrosion of polyurethane under the impact of water is mostly based on the so-called hydrolytic degradation where the sapofication of the material occurs. In combination with the dynamic load the refractory material, which is in microscopic range, is worn out comparatively quickly during the further rolling off and under the impact of slip.

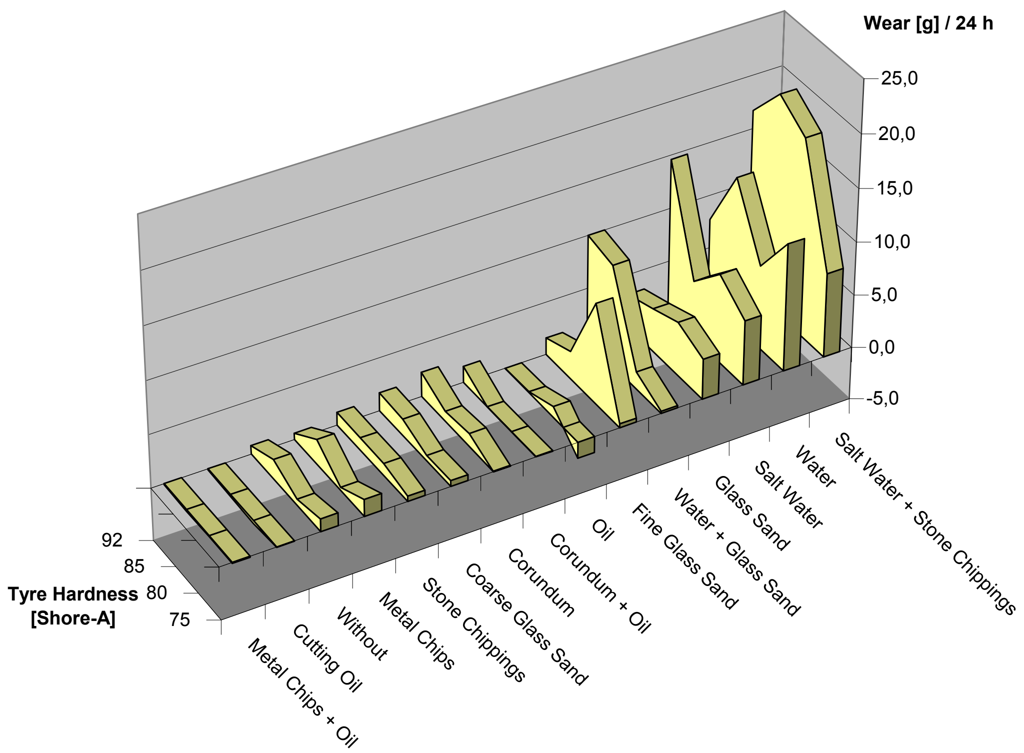

Figure 5. Abrasion under impact of intermediate materials in 24 hours

2.3 Tread delamination

The damage mechanisms like thermal overload, or abrasion which lead to the breakdown of the wheels, have been analysed in many research projects. However the failure of the joint area has not been tested yet.

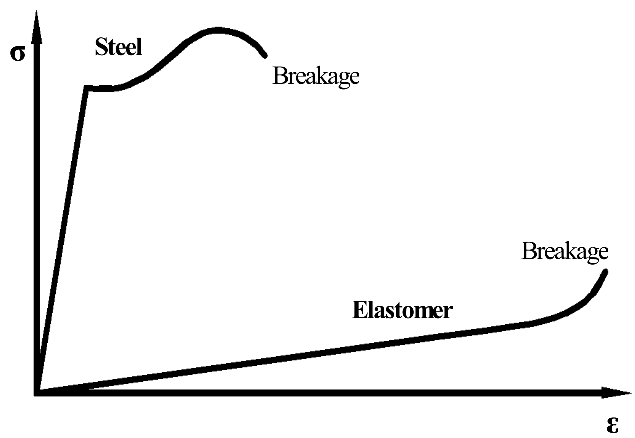

Figure 6. Different tension and expansion behaviour of steel and elastomer

Due to the various expansion behaviour of elastomer and body in the joint area between both components there is a stiffness difference. This unsteadiness in the elongation run leads to higher tensions which especially occur on the edges and on the smaller thicknesses of the massive polyurthan tyre. Consequently the partial groove is a weak point which often causes the material bond to fail. Apart from the external load the thickness and the hardness of the tread are basic influencing variables on the tension in the partial groove. The harder and thinner they are, the higher the tensions are.

A cohesion fracture in the range of elastomer is called an R-defect (rubber). If the bond of elastomer and adhesive cement gets separated, it is an RC-defect (rubber-cement). It is a CP-defect, if the adhesive cement and the primer break. An M-defect means that the adhesive cement solves from the metal (Figure 7).

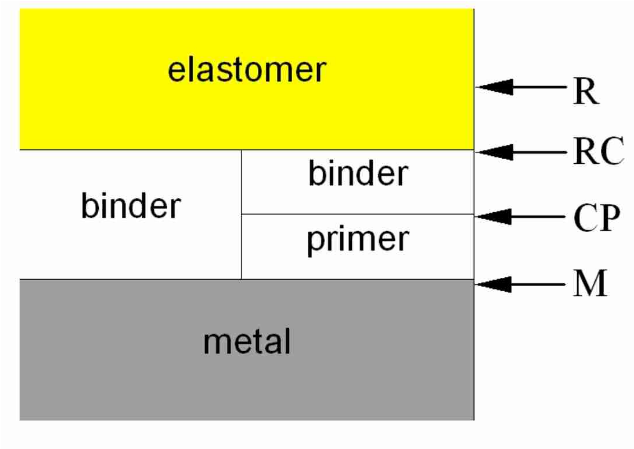

Figure 7. Schematic assembly of a bonding

Mistakes and loading rates which can effect the damage process are shown in the following table:

Table 1. Influence factors to the damage process of tread delamination

Kind of defect	Pre-damage	Load	Covering	External impact
Defect adhesive agent Inclusion of contaminants Diminished surface performance of the body Air pockets in the synthetic material Pollutions (e.g. grease, silicone)	Size Form Position	Normal force speed Track Camber	Hardness Geometry surface of the hub Material Adhesive agent	Temperature Atmospheric moisture Intermediate material

3. Current research

In current researches the bonding mechanism of the massive polyurthane tread on the metal hub and its damage behaviour is going to be analysed. Beyond in use of wheels, PU has a very wide field of application. So the results can also be transferred to other polymer-metal-bonding applications, for example to coupling elements etc.

It is intended to develop a concept to assess the bindings regarding the durability and the damage run. Next a model is to be made available which has the potential to show the damage run and the durability realistically via the recorded actual state of the material bond in the non-destructive test methods. Reversely the gained results should increase the durability by keeping the boundary conditions (e.g. manufacturing and loading parameters).

For these examinations a roller test station has been developed to realise the dynamic loads. A multi-axle tension condition is achieved in the bonding groove of the bonding material by the load (Figure 8). The test station is built for multiple - at the same time loaded - sample bodies to reach a

most possibly high statistical confidence level. The loads of the bodies are controlled by a computer. The rolling cruise, the normal force, the camber, and the track can be varied. For controlling the test run the cruise, normal force, radial and tangential forces are permanently measured. The radial motion is listed by a position encoder while the temperature is controlled via an infrared thermometer.
In defined intervals the wheels on the station get loaded. Between the load intervals the appearing defects are analysed via non-destructive test methods.

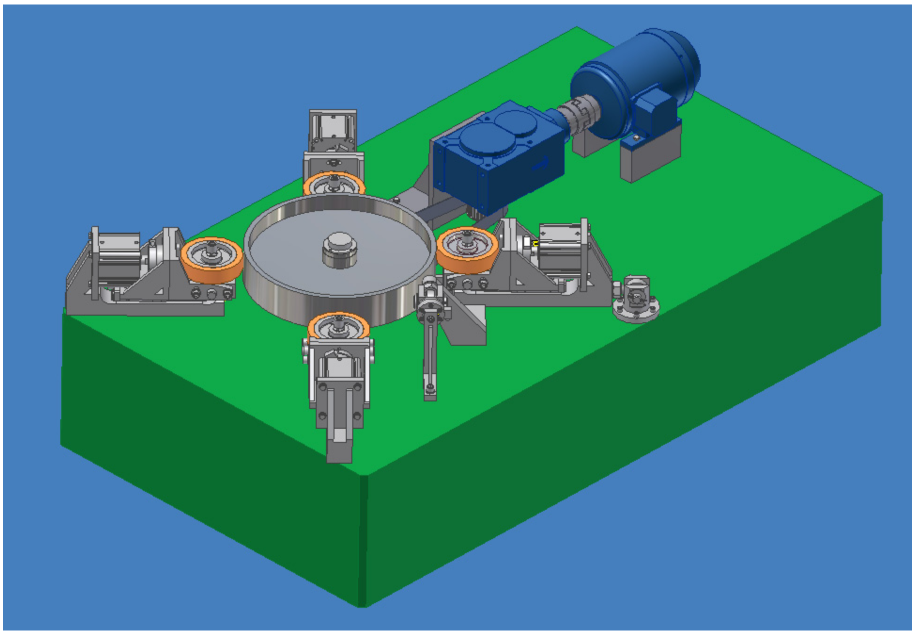

Figure 8. wheels test station for loading the testing wheels

The ultrasonic technique is approved as a test method in examinations of delaminations on the interface between the elastomer and the metal. Even smaller delaminations are detectable, as long as they show a crack of only a few nm.
During the tests the sample edges with partial delaminations were scanned lying in a water basin. Here the water is used as a coupler medium. The results are presented as a C-picture (amplitude) and D-picture (running time) (Figure 9, left and middle). After the ultrasonic examination the polyurethane layer of the sample was removed to show optically the dimensions of the binding defects and to photograph them (figure 9, right).

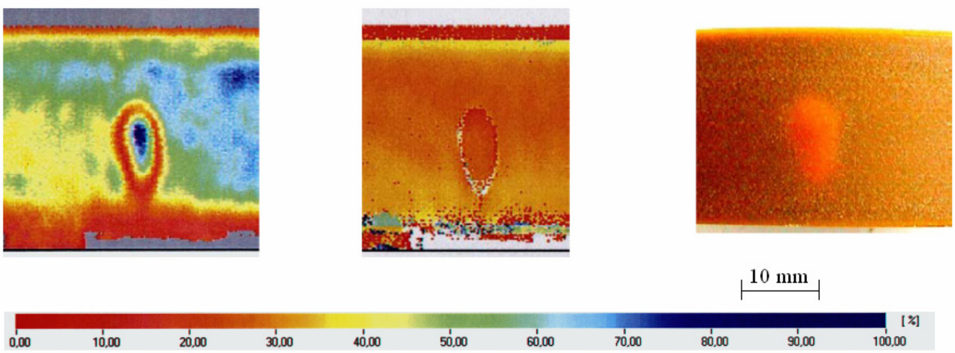

Figure 9. ultrasonic scan of delamination. C-picture (l.), B-picture (m.) and photograph (r.)

The results of the ultrasonic examination were close to the realistic defect types so that the damage run could be observed.

4. Conclusion

The logistic requirements have extremely risen in the last few years and the damage of wheels in material handling equipment has become a big problem. Different boundary conditions and factors of the influence of heavy load wheels in such systems can lead to different damage mechanisms.
High-speed and high weight loaded wheels are destroyed by an inner heat-build-up. The technical designers of conveyor systems should pay attention to the maximum of the load capacity of the wheels.
In particular, the existence of abrasive or chemical materials lead to a fast wear by abrasion in use of logistic systems. Especially in wet environment the wear of PU is very high. In such cases wheels made of different material, e.g. rubber should be used. Beside this, PU has a bad coefficient of friction on wet surfaces anyway.
The causes of the delamination of the massive tread is the most frequent sudden breakdown of a heavey load wheel. However their damage process has not been finally investigated yet. Therefore a non-destructive testing method must be developed.
In realising the causes and the behaviour of such wheels, the users of logistic systems are able to tune the wheels to the estimated boundary conditions and operational areas, for example a load handling attachment of an automatic high bay warehouse can be designed accurately for theses conditions. On the other hand, a higher life-time and smaller costs of wheels can be obtained by using the knowledge of the resarches to optimise the wheels through the manufacturers.

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