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Material behaviour

Ballistic and numerical simulation of impacting goods on conveyor belt rubber

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ABSTRACT

Impact loading is an important process in the transport industry as it causes wear and failure of critical components. Conveyor belts are of particular importance as they are used in practically every industry where large quantities of goods are moved over short (<10 m) or long distances (>1 km). To investigate stress levels inside the material during impact loading, a gas gun was utilized to shoot 9 mm spherical steel balls onto the surface of a rubber conveyor belt. A high speed video recording system was employed in order to determine penetration depth and dissipated energy of the steel ball. Maximal penetration depths of up to 3.9 mm and maximal dissipated energies of up to 86.8 % were measured. Additionally, a numerical simulation using smooth particle applied mechanics was conducted and compared to the experimental results obtained with the gas gun. The calculated von Mises stresses affected the conveyor belts up to a maximum depth of 8.8 mm with at least 20 MPa. Maximum von Mises stresses were calculated to reach 60 MPa.

1. Introduction

Wear and failure of critical components are major concerns in every industry. Therefore, preventing or slowing down wear is one of the most important, but also most challenging, aspects of design. In this case, the loading process of rubber based conveyor belts is of particular interest. Depending on the application, conveyor belts can be loaded with hundreds of tons of goods every hour, which causes elastic, as well as plastic, deformation of the material and, over time, wear. The belt can make up to 70 % of the total costs of a transport system (calculated as cost per lifetime) [1], emphasising the importance of its wear resistance.

To tackle this problem, one must first understand the process of loading and impacting. One option is to run a large number of tests and experimentally simulate every possible outcome. Unfortunately, this is very time-consuming and expensive and, in most cases, impracticable. An elegant solution is a numerical simulation, which can quickly deliver values for set parameters once a suitable model has been chosen and corresponding code written. Such simulation can also give insight on phenomena that are not directly accessible via practical experiments, such as stress inside the material, change of contact geometry or tribo-chemical effects [2]. Of course, there is still a need for experimentally acquired results to validate the chosen model.

Over the years, different experimental setups have been designed to test materials for their impact related properties, generating data that can be used to compare with data from numerical simulations. Wang et al. [3] used a high-speed crash system, where a trolley was accelerated by an elastic rope onto a rigid wall. A numerical simulation with a finite element model provided validation of data. Another possible setup includes a gas gun to simulate single particle impact, which was reported by Apostol et al. [4]. Currently,

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impact simulations are used to predict impact-related wear due to erosion [5,6], blast resistance [7] and ballistics [8].

In literature, numerical simulations, whether they are based on continuum, discrete or statistical methods, are often utilized in modelling tribological phenomena to enhance understanding of problems that are not accessible through experimental approaches alone [9]. It is also possible to model such phenomena with a particle-based method: the smoothed particle applied mechanics (SPAM), as described recently by Sun et al. [10]. This method relies on particles shifting around a defined grid according to equations of motion. The physical properties being investigated are gained through interpolation between these mass-carrying particles. Since the interpolation is a summation of the influence by neighbouring particles, they do not carry volume elements, but parts of it, and summation gives the quantity investigated. SPAM-related models have been used successfully in the past by Johnson et al. [11] to simulate impacts. Compared to simulation methods like finite elements, SPAM can deal more efficiently with large deformations, which are expected when investigating rubber, and offer better accuracy in such situations.

Depending on the kinetic energy of the impacting ball, wear and damage mechanisms can differ greatly. Thus, the model must be adjusted to the specific material pairing and kinetic energy. A visco-elastic model is needed in this case, as the objects being investigated are rubber conveyor belts. A couple of models have been used in literature to simulate visco-elastic impact [12]. For modelling linear visco-elasticity, the well-established Kelvin-Voigt model and the Maxwell model can be used as a basis. This work will utilize the Kelvin-Voigt model, which includes a purely viscous dampener and a purely elastic spring. The SPAM model will contain a purely elastic material together with a viscous term, representing spring and dampener.

Therefore, this work will focus on understanding the impact situation, with an emphasis on the stresses present during the loading process of rubber conveyor belts. In contrast to other works, which concentrate on homogenous materials to reduce the number of interpretable parameters, this work tries to take the influence of the carcass into account, which more accurately reflects the practical usage of conveyor belts.

2. Experimental

2.1. Materials

A basic schematic is shown in Fig. 1, illustrating the complex makeup and material combination of a state of the art conveyor belt, which is composed of: A 4 mm thick rubber top layer and three layers of an interwoven polyester(warp)-polyamide(weft) carcass with skim layers (made of soft rubber) between them to improve the tensile strength of the belt. A 2 mm rubber bottom layer completes the conveyor belt and provides sufficient friction to the drive pulley during service.

Two commercially available Styrene-Butadien-Rubber (SBR) based conveyor belts, Semperit Multiply D (Sample A) and Transconti NQ (Sample B), were chosen for these experiments. Additionally, Semperit N17 was selected (Sample C). This particular belt is also SBR based and features additionally a deforming fleece for better processing. Shore A hardness was measured for all three samples and revealed values of 65, 63 and 71 for Samples A, B, and C, respectively.

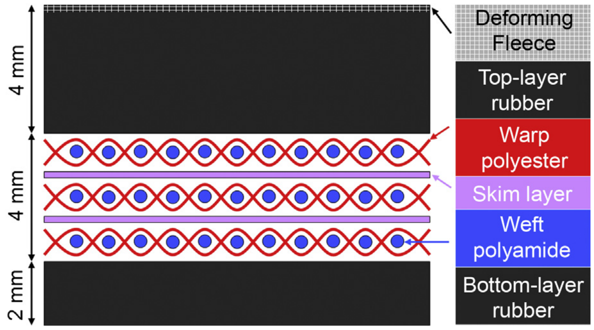

Fig. 1. Schematic cross-section of a state of the art conveyor belt.

Square plates, with lateral dimensions of 180 × 180 mm and a total thickness of 10 mm, were sawn from of the original conveyor belts. These samples were then fixed to a tiltable table using steel clamps.

2.2. Impact testing

The impact tests at high velocity were performed using a High Velocity Particle Impactor (HVPI). A schematic drawing of the device is presented in Fig. 2. The HVPI consists of a smooth bore barrel connected to a pressurised air tank so that 9 mm balls of various materials can be launched onto prepared samples. To monitor the velocity at impact, a speed measurement device was placed just before the target assembly. The target assembly is angled at 45° and consists of the samples fixed onto a steel support with clamps. The impact was monitored by a high speed camera and evaluated for subsequent analysis.

The HVPI device uses pressurized air to launch spherical projectiles in a controlled manner against a piece of conveyor belt placed at 1 m distance from the end of the barrel. A stainless steel ball of 9 mm in diameter and 2.98 g in weight was used as a projectile. The projectile balls were fired against the samples at a constant velocity of 37 m/s, which corresponds to a kinetic energy prior the impact of 2.04 J. The incident velocity of the projectile was measured by a commercial timing device placed in front of the target assembly. The impact tests were performed at an angle of 45° with a precision of ±1°. Each sample was impacted ten times to observe effects of hysteresis or damage caused by previous impacts and to ensure statistical significance.

The fractions of dissipated energy of the initial kinetic energies, maximum penetration depths and reflected angles were determined by analysing several overlapping high speed images. Fig. 3 illustrates the overlapping technique, where the yellow dash-dot line defines the impact surface (zero line) and the blue circles highlight the surface of the impacting steel ball.

To calculate the exit velocity, the distance travelled (Δs) between frames after the impact event was calculated by tracking a specific point, such as the centroid of the ball.