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EXPERIMENTAL AND MATHEMATICAL ANALYSIS OF STATIC TENSILE BEHAVIOR OF CONVEYOR BELTS AT DIFFERENT STRAIN RATES

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Abstract

The mechanical behavior of conveyor belts under static loading conditions is a key factor in evaluating their operational reliability and structural integrity. This study presents an expanded analysis of experimental tests carried out on textile conveyor belt specimens subjected to controlled static tensile loading at three different strain rates, with the objective of examining how variations in loading speed influence the overall stress–strain response. The experiments were performed on a universal tensile testing machine, where force and elongation were continuously recorded throughout the testing procedure, enabling the construction of accurate stress–strain diagrams for each examined strain rate. These results allowed for a detailed comparison of the mechanical behavior of the specimens, with particular focus on differences in stiffness, deformation capacity, and ultimate load-bearing performance. In parallel with the experimental work, a mathematical model describing the belt's stress–strain relationship was formulated using the measured data; the resulting fitted curves demonstrated a very high level of agreement with the experimental results. The combined methodology applied in this research highlights the importance of integrating experimental testing with model development to achieve a more comprehensive understanding of conveyor belt behavior.

***Keywords**: conveyor belt, static tensile test, strain rate, stress–strain behavior, mathematical modeling*

1 INTRODUCTION

The mechanical performance of conveyor belts under static loading conditions represents a critical aspect of conveyor system design, maintenance, and lifetime prediction. Despite their widespread industrial use, the influence of strain rate on the tensile behavior of conveyor belt materials remains insufficiently characterized, particularly for textile-reinforced belts in which viscoelastic and rate-dependent phenomena play a significant role. Previous studies on polymeric and composite materials have demonstrated that variations in loading rate can substantially alter stress–strain responses, stiffness, and ultimate strength, underscoring the need for a more detailed understanding of how these effects manifest in conveyor belts. However, existing research often focuses either on general viscoelastic behavior or on dynamic loading conditions, leaving a gap in systematic analyses of static tensile performance across different strain rates. In response, this study combines controlled experimental testing with mathematical modeling to examine how three distinct strain rates affect the tensile behavior, deformation characteristics, and ultimate load-bearing capacity of textile conveyor belt specimens. By integrating empirical data with a predictive stress–strain model, the work aims to provide a comprehensive and reliable basis for interpreting rate-dependent mechanical responses, ultimately contributing to improved design, maintenance strategies, and predictive assessment of conveyor belt service life.

2 LITERATURE OVERVIEW

The behavior of conveyor belts under static testing is strongly influenced by strain rate, which directly affects tensile strength, stiffness, and deformation characteristics. Numerous studies have confirmed this dependency, particularly through observations of viscoelastic responses during tensile loading. Increasing the tensioning speed generally leads to higher tensile strength and reduced ultimate elongation, as shown in thermoplastic elastomers where elongation decreases from 800 ± 50% at 200 mm/min to 650 ± 70% at 10 mm/min [1]. Similar rate-dependent, nonlinear stress–strain behavior has also been reported for lightweight textile conveyor belts [2]. The viscoelastic nature of rubber-based composites is further demonstrated through stress relaxation and creep effects observed at different loading rates [3,4], as well as through investigations of ABS materials where loading rate and time under tension significantly influence mechanical performance [5]. These time-dependent properties play a critical role in understanding damage progression and operational deformation of conveyor belts. Other studies have shown that operational factors such as applied tension and loading rate substantially affect composite mechanical properties [6], while variations in temperature and thermomechanical history also influence structural behavior under industrial conditions [7]. Dynamic mechanical analyses of polycarbonate materials demonstrate strain-rate sensitivity and the formation of master curves, indicating thermorheological simplicity and suggesting similar behavior may appear in conveyor belt materials under dynamic loading [8]. Overall, research consistently shows that variations in strain rate affect stress–strain response, durability, and long-term performance of belt carcass and rubber layers, particularly when evaluated through combined fatigue experiments and numerical modelling [9]. Recent work on condition-based maintenance further emphasizes the need for accurate mechanical characterization. Modern diagnostic methods support maintenance decisions by linking material behavior under load with service-life predictions, reinforcing the importance of understanding strain-rate effects in static tensile testing [10].

3 MATHERIAL AND METHODS

The aim of the static testing was to examine how different strain rates affect the tensile behavior of textile conveyor belts under controlled conditions. Static tensile tests provide a clear view of the belt's immediate mechanical response when loaded at a predefined speed, which is important because real conveyor belts experience both slow and rapid tension variations during operation. Since the rate of tension build-up influences short-term deformation, specimens were tested at three strain rates representing low, medium, and high loading speeds. The resulting stress–strain curves enabled direct comparison of stiffness, ultimate strength, and elongation, revealing systematic differences and supplying essential data for modeling and predicting belt performance under operational conditions.

3.1 Methods

The testing device is consisted of the worm gear screw jack (1), connecting shaft (2), helical geared electric motor (3), rotary encoder (4), fatigue testing module (5), upper jaw (6), belt sample (7), lower jaw (8), load cell (9) and supporting frame (10) figure 2. The device characteristics are:

- maximum load for static testing of samples: 50.000 N;
- maximum travel during static testing: 700 mm;
- maximum speed of static tensioning: 100 mm/min;

Conveyor belt testing was done on a specially constructed device for this testing, UZITT MKM 5000, Figure 1.

***Fig. 1** UZITT MKM 5000 during experiments*

The elements of the device are shown in Figure 2.

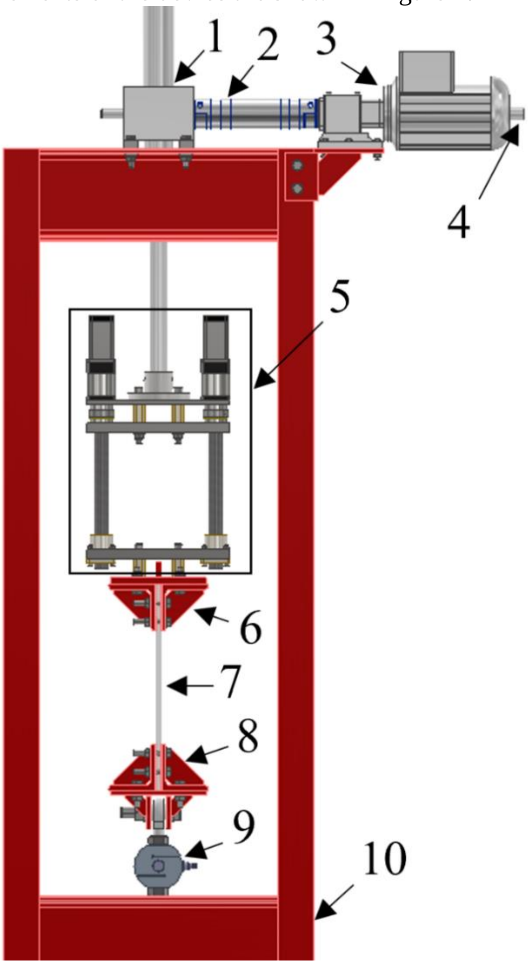

***Fig. 2** Elements of the testing device*

3.2 Matherials

The conveyor belt whose load bearing layer was made by plain weaving was tested. The warp threads are made of polyester, while the weft threads are made of nylon. This type of load bearing layer is known as EP. The designation of the conveyor belt is EP 500/3 Y 526858. The characteristics of the belt are given in Table 1.

Table 1 Characteristics of the selected belt from the manufacturer's datasheet.

Characteristic	Unit	Min	Max	Value
Breaking strength longitudinally	N/mm	500	-	523
Elongation at break	%	12	-	29,5
Working elongation – 10%	%	-	1,5	1,34
Adhesion top cover / 1st ply	N/mm	3,5	-	4,4
Adhesion 1st ply / 2nd ply	N/mm	5	-	7,6
Adhesion 2nd ply / 3rd ply	N/mm	5	-	6,8
Adhesion bottom ply / bottom cover	N/mm	3,5	-	4
Tensile strength of cover	N/mm^2	20	-	20
Elongation of cover	%	400	-	522
Abrasion resistance	mm^3	-	130	122

4 RESULTS AND DISCUSSION

4.1 Results

Since the conveyor belt specimens were tested in tension, their mechanical response was influenced by the applied strain rate. At the beginning of the testing program, the specimens were stretched at different strain rates until failure: 0.2 mm/s (0.00083 s^{-1}), 0.9 mm/s (0.00375 s^{-1}), and 1.6 mm/s (0.0066 s^{-1}), which represented the tensioning speeds prescribed by the standard governing tensile testing of conveyor belts. The force–elongation curves were subsequently transformed into stress–strain curves for further analysis. In addition, the results were adjusted by removing the initial straightening zone, as this portion of the material response was not relevant to the objectives of the study. The resulting curves are presented in figure 3.

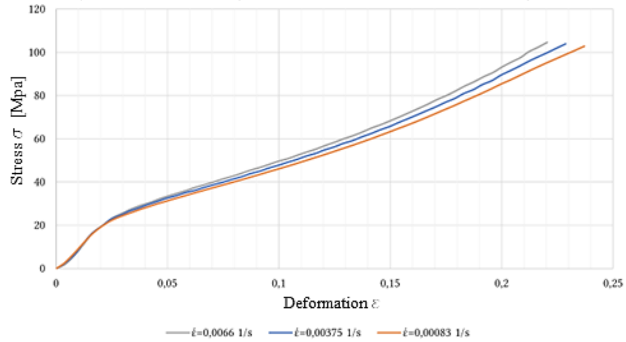

Fig. 3 Stress–strain curve of the EP 500/3 conveyor belt

The figure clearly shows that no differences in the behavior of the conveyor belt specimens occur up to a stress level of 20 MPa and a strain of 0.02, i.e., within the elastic region. Divergences appear later, in both the mild and the steep plastic zones. The maximum stress of 104.6 MPa was reached at the highest strain rate of 0.0066 s^{-1}, whereas the maximum strain of 0.237 occurred at the lowest strain rate of 0.00083 s^{-1}. This indicates that at lower strain rates the effects of material creep are more pronounced, leading to a reduction in the load-carrying capacity of the material.

The raw data were fitted using a quadtratic polynomial, which was found adequate to capture the shape of the stress–strain response in the strain interval 0–0.24. The fitted curves yielded high coefficients of determination ($R^2 \approx 0.99$), confirming that a quadratic polynomial is sufficient for representing the mechanical behaviour within the investigated range. The results are given in figures 4-6.

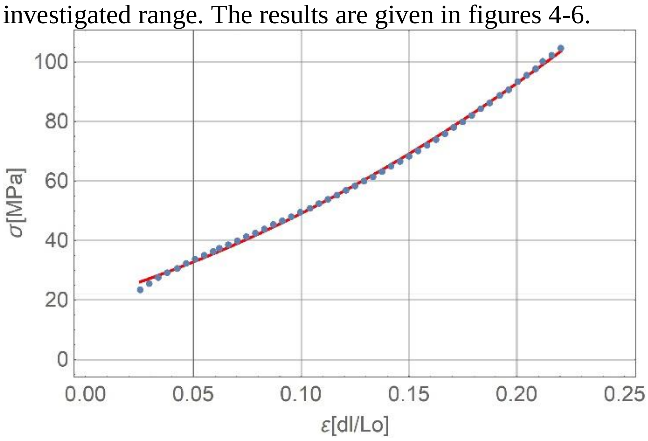

Fig. 4 Quadtratic fit for the strain rate of 0,0066 1/s

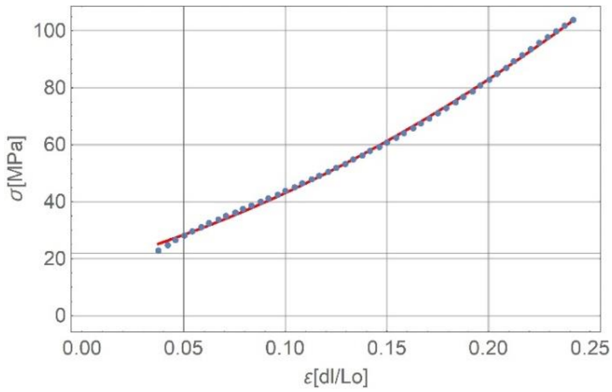

Fig. 5 Quadtratic fit for the strain rate of 0,00375 1/s

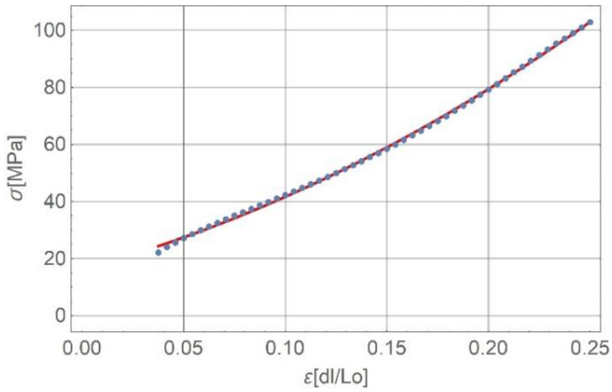

Fig. 6 Quadtratic fit for the strain rate of 0,00083 1/s

4.2 Modelling Approach

For each strain rate, the stress–strain data were fitted using the quadratic expression:

$$\sigma(\varepsilon) = a\,\varepsilon^2 + b\,\varepsilon + c \qquad (1)$$

The obtained coefficients are given in Table 1.

Table 2 Obtained coefficients

Strain rate $\dot{\varepsilon}$ (1/s)	a	b	c	R^2
0.00083	336.8898	290.7959	13.7123	0.9912
0.00375	359.6770	303.0674	14.0136	0.9902
0.00660	347.2506	322.8742	13.9549	0.9893

All three fits showed excellent agreement with the recorded data.

To quantify the influence of strain rate on the mechanical response, the polynomial coefficients (a, b, c) were expressed as linear functions of $\dot{\varepsilon}$:

$$\begin{aligned} a(\dot{\varepsilon}) &= 340.77 + 2878.33\dot{\varepsilon} \\ b(\dot{\varepsilon}) &= 286.69 + 5440.89\dot{\varepsilon} \\ c(\dot{\varepsilon}) &= 13.74 + 41.39\dot{\varepsilon} \end{aligned} \qquad (2)$$

By substituting these expressions into the quadratic polynomial, the following empirical strain-rate-dependent constitutive law is obtained:

$$\boxed{\begin{aligned} \sigma(\varepsilon,\dot{\varepsilon}) = (340.77 + 2878.33\,\dot{\varepsilon})\varepsilon^2 + \\ (286.69 + 5440.89\,\dot{\varepsilon})\varepsilon + (13.74 + 41.39\,\dot{\varepsilon}) \end{aligned}} \qquad (3)$$

4.3 >Discussion

The obtained constitutive law clearly indicates that all polynomial coefficients increase with strain rate, which is consistent with the viscoelastic nature of reinforced rubber materials.

The coefficient *b*, which dominates the near-linear portion of the curve, increases significantly with strain rate from 290.8 MPa at 0.00083 s^{-1} to 322.9 MPa at 0.0066 s^{-1}.

This reflects an increase in apparent stiffness when the material is deformed more rapidly. Physically, this is consistent with limited relaxation time of the polymer-rubber matrix at higher loading speeds.

The coefficient *a*, associated with nonlinear hardening, also increases with strain rate (with a minor deviation at the highest rate). This suggests that the material demonstrates enhanced strain stiffening when loaded more rapidly, further confirming its rate-dependent behavior.

All three curves maintain a similar shape, but their slopes and curvature increase with strain rate. This demonstrates that the strain-rate effect in conveyor belt rubber-textile composites is both quantitative (higher stresses at equal strains) and functional (change of curvature → shift in mechanical regime).

The proposed empirical model is simple, fully data-driven, highly accurate (R^2 very close to 1), suitable for engineering prediction within the tested strain domain, usable for life-prediction studies where strain history and deformation speed must be accounted for. This makes it valuable for structural simulations, conveyor belt design, and comparative material studies.

5 CONSLUSION

This study examined the static tensile behaviour of textile-reinforced conveyor belts at three different strain rates to assess how loading speed influences the stress–strain response and overall mechanical performance of the material. The experimental results revealed clear rate-dependent behaviour: while the elastic regions of all curves were nearly identical, significant differences emerged in the plastic domain. Higher strain rates produced increased stiffness and higher maximum stress values, whereas lower strain rates resulted in greater total elongation, reflecting more pronounced time-dependent deformation processes such as creep. Quadratic polynomial fitting of the experimental curves yielded excellent agreement with the measured data ($R^2 \approx 0.99$), confirming that the material response in the examined strain interval can be accurately captured using a second-order model. By expressing the polynomial coefficients as linear functions of the strain rate, a compact empirical constitutive law was developed to describe the combined influence of strain and strain rate on the stress response.

This model successfully captures both the quantitative increase in stress at equal strain values and the functional change in curve shape across different loading rates. The results highlight that the mechanical behaviour of conveyor belts cannot be fully described without considering strain-rate effects, which are directly relevant to operational conditions such as start-up, breaking, and transient loading events. The developed empirical model provides a practical and reliable tool for predicting belt performance under varying loading speeds and can support engineering applications including conveyor system design, durability assessment, and predictive maintenance strategies.

Future research should extend this analysis to dynamic loading conditions and include fatigue-related effects to build a more comprehensive understanding of belt behaviour throughout its service life.

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REFERENCES

1. Frick, M., Zalusky, A., Hillmyer M., 2003, *Characterization of polylactide-b-polyisoprene-b-polylactide thermoplastic elastomers*, Biomacromolecules 4(2), pp. 216-223.
2. Wang, Ze Xing, Jinhua Jiang, and Nan Liang Chen, 2011, *Nonlinear rate-dependent stress-strain behavior of light-weight textile conveyor belt*, Materials Science Forum, 675-677, pp.453-456.
3. Pihnastyi, O., Cherniavska, S., 2021, *Using the asymptotic approximation of the maxwell element model for the analysis of stress in a conveyor belt*, Eastern-European Journal of Enterprise Technologies 7(6), pp. 77-84.
4. Nagy, T., Vas M., 2007, *Relationship between constant strain rate and stress relaxation behavior of polypropylene*, Express Polymer Letters 1(2), pp. 84-91.
5. Sudduth, D., 2003, *Comparison of the viscous and elastic components of two abs materials with creep, stress relaxation and constant strain rate measurements using the universal viscoelastic model*, Journal of Applied Polymer Science 90(5), pp. 1298-1318.
6. Rudawská, A., Madleňák, R., Madleňáková, Dróździel, P., 2020, *Investigation of the effect of operational factors on conveyor belt mechanical properties*, Applied Sciences 10(12), 4201.
7. Klompen, J., Engels, T., Govaert, L., Meijer, P., 2005, *Modeling of the postyield response of glassy polymers: influence of thermomechanical history*, Macromolecules 38(16), pp. 6997-7008.
8. Koomson, C., Zeltmann, S., Gupta, N., 2018, *Strain rate sensitivity of polycarbonate and vinyl ester from dynamic mechanical analysis experiments*, Advanced Composites and Hybrid Materials 1(2), pp. 341-346.
9. Ilanković, N., Živanić, D., Zuber., 2023, *The Influence of Fatigue Loading on the Durability of the Conveyor Belt*, 5(13), 3277.
10. Błażej, R., Jurdziak, L., Rzeszowska A., 2025, *Condition Based Conveyor Belt Maintenance and Refurbishment*, Preprints.

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