EVALUATION OF THE RELIABILITY OF THE CARPET BELT WITH TEXTILE INSERTS, COMPONENT OF THE BELT CONVEYOR AT ROSIA POIENI QUARRY

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Abstract: The objective of this paper is to evaluate the main reliability indicators for the car-pet belt with textile inserts EP 250/5 (EP 1250) from the roller belt conveyors. In-dicators the main factors of operational reliability are determined based on the statistical processing of times between failures strip carpets. The reliability of the belt conveyors determines the overall reliability of the conveyors with tape.

Keywords: roller belt conveyor, belt carpet with textile inserts, failure, statistical calculation, reliability indicators.

1. INTRODUCTION

The B1 and B5S roller belt conveyors are part of the five belt conveyor system on rollers arranged in cascade, known as strip relay. The system ensures the transport of the ore of copper from the crushing station to the preparation plant warehouse.

The roller belt conveyor B1, figure 1, provides a conveying length of 110 m, horizontally, in free atmosphere. The transport capacity of the conveyor is 2800 t/h, at a speed of 4.1 m/s, with the power installed of 2×110 kW.

The B5S pick-up and deposit belt conveyor, figure 2, carries out the deposit-ing of the ore in the stockpile of the preparation plant. The transport length is 32 m, with a lifting height of 6 m. The capacity of transport is 2800 t/h, at the speed of 4.1 m/s, with the installed power 2×110 kW. [1]

The analysis of the faults that appear on the two conveyors shows that the convey-or belt is the subassembly which decisively influences their functionality. By

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con-veyor belt is meant the assembly consisting of the strip carpet with textile inserts and the related hot vulcanizations. [2]

Fig. 1. Drive station of conveyor B1

Fig. 2. Pick-up and deposit conveyor B5S

On the B1 conveyor, the belt carpet with textile inserts is 1400 mm wide, 20 mm thick and class resistance EP250/5 (EP 1250). The length of the conveyor belt is approximately 240 m. The belt is formed from a single section. Such a section of carpet is recognized in the database as tape drum, according to the form in which the tape carpet is delivered by the manufacturer. Joining the ends the carpet is ma-de by hot vulcanization. It follows that the conveyor belt consists of a drum of tape and a vulcanization. [3]

During the follow-up period in operation of the conveyor, the frequency of occurrence of vulcanization is low so their contribution to the quantification of conveyor belt reliability can be neglected. Under these conditions, the reliability of the conveyor belt, and implicitly of the B1 conveyor, is defined by the reliability of the conveyor belt.

On the B5S conveyor belt with textile inserts of the same resistance class EP 250/5 has a width of 1600 mm and a thickness of 22 mm. The length of the con-veyor belt is approximately 80 m. It is formed from a single section of strip carpet and a single vulcanization.

The reliability of the belt conveyor, and implicitly of the B5S pick-up and deposit conveyor, is defined by the reliability of the carpet tape.

2. EVALUATION OF THE RELIABILITY OF THE BELT CONVEYOR EP 250/5 IN THE COMPOSITION OF THE CONVEYOR B1[5]

2.1. Database [4]

The database is created from the daily reports of the process operators on the activity corrective maintenance. Table 1 shows the actual operating times until a drum is out of service band.

The result is the statistical series consisting of n = 4 terms representing the times, ti, of operation until wear over the allowable limit of the tape carpet, in hours, 4797, 4983, 5082, 8482.

Table 1. *Actual run-to-failure times of tape drums*

Nr.crt.,i	Name of work	Date of installation	Actual operation time, ti, h
1	Inserting tape drum	21.04.2012	4983
2		27.11.2014	8482
3		20.09.2018	5082
4		28.08.2020	4797

The series is relevant even though it only has four terms because the product tracking period is long.

2.2. The empirical defect distribution function, $\hat{F}(ti)$

The empirical distribution function of the belt carpet failures, also called the experimental function, is determined with the estimator Fi=i-0,45/n+0,3. Its evolution is presented in table 2.

Table 2. *Empirical defect distribution function*

i	t_i, h	$\hat{F}(t_i)$	i	t_i, h	$\hat{F}(t_i)$	i	t_i, h	$\hat{F}(t_i)$	i	t_i, h	$\hat{F}(t_i)$
1	4797	0,056452	2	4983	0,137097	3	5082	0,217742	4	8482	0,298387

2.3. Theoretical failure distribution function, failure function, F(t)

The theoretical defect distribution function that best characterizes the strip functionality is expressed by the triparametric Weibull distribution $F(t) = 1 - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$, where β is the dimensionless parameter of form, η the real scale parameter, measured in hours, γ the initialization parameter, expressed in *hours*.

The distribution parameters are estimated by the method of moments.

The shape parameter β = 6.965 is obtained by solving the equation

$$\sqrt{\Gamma\left(\frac{2}{\beta}+1\right) - \left[\Gamma\left(\frac{1}{\beta}+1\right)\right]^2} - \frac{\sigma}{m} = 0. \tag{1}$$

In this relationship σ = STDEV (t_i) = 293 hours is the standard deviation, or root mean square deviation of the times of operation of the tape drums, and m = AVERAGE (t_i) = 1737 *h* is the average of the same operating times.

The real scale parameter η = 1857 *h* and the initialization parameter γ = 2,7E-04 *h* are obtained as a function of the parameters m, σ and β.

The conveyor belt failure function, F(t), for the B1 conveyor, is

$$F(t) = 1 - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} = 1 - \mathrm{e}^{-\left(\frac{t - 2{,}7E\text{-}04}{6469}\right)^{3{,}674}} \tag{2}$$

Applying the Kolmogorov-Smirnov distance concordance test to the triparametric Weibull distribution leads to the relationship,

$$\max_{1\leq i\leq n}\left\{\left|F(t_i)\text{-}\widehat{F}(t_i)\right|,\left|F(t_i)\text{-}\widehat{F}(t_{i-1})\right|\right\} = 0{,}340114 < D_{\alpha,\,n} = D_{0{,}5\,,n} = 0{,}776393 \tag{3}$$

This relationship demonstrates that the triparametric Weibull distribution is validated with a confidence level of 99.5%, the risk α being only 0.5%.

It is specified that the following are also validated:

- exponential distribution, with failure intensity parameter, λ, determined by the method of the smallest squares;
- the normal distribution, where the parameters mean m and standard deviation σ are estimated by the method of maximum likelihood;
- the biparametric Weibull distribution, with the shape parameter β and the real scale parameter η estimated by the method of least squares.

Criteria used to adopt the distribution that best characterizes band functionality are the dispersion and the difference between the empirical and the theoretical distributions. Those distributions are adopted for which dispersion and variance have the smallest values.

Dispersion is a measure of the centering of values with respect to the mean (median) value, which is considered a be the value closest to the actual value.

The triparametric Weibull distribution with the smallest dispersion value is adopted.

2.4. The main reliability indicators of the belt carpet EP 250/5

Table 3 and figures 3, 4 and 5 summarize the main reliability indicators for the belt carpet EP 250/5 of the B1 conveyor, and implicitly for the B1 roller belt conveyor as a whole.

Table 3. **The main reliability indicators of the belt carpet with textile inserts EP 250/5 as part of the roller belt conveyor B1**

Nr. crt.	**Name and symbol Indicator**	**Calculation relation**	**Value, UM**
1	Reliability function, RB1(t)	$R_{B1}(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} = e^{-\left(\frac{t-2{,}7E\text{-}04}{6469}\right)^{3{,}674}}$ (4)	Fig. 3
2	The probability density function of the time between failures, fB1(t)	$f_{B1}(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} = \frac{3{,}674}{6469}\left(\frac{t-2{,}7E\text{-}04}{6469}\right)^{2{,}674} e^{-\left(\frac{t-2{,}7E\text{-}04}{6469}\right)^{3{,}674}}$ (5)	Fig. 4
3	The breakdown intensity function, zB1(t)	$z_{B1}(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} = \frac{3{,}674}{6469}\left(\frac{t-2{,}7E\text{-}04}{6469}\right)^{2{,}674}$ (6)	Fig. 5
4	Mean time between failures, MTBFB1, E(T)B1	$E(T)_{B1}=\gamma+\eta\cdot\Gamma\left(\frac{1}{\beta}+1\right)=2{,}7E\text{-}4+6469\cdot\Gamma\left(\frac{1}{3{,}674}+1\right)$ (7)	5836 *h*
5	Median time between failures, t0.5;B1, tmed;B1	$t_{0,5;B1}= \gamma+\eta\sqrt[\beta]{-\ln 0{,}5} = 2{,}7E\text{-}4+6469\cdot\sqrt[3{,}674]{-\ln 0{,}5}$ (8)	5855 *h*
6	Dispersion of time between failures, DB1	$D_{B1} = \eta^2\left\{\Gamma\left(\frac{2}{\beta}+1\right)-\left[\Gamma\left(\frac{1}{\beta}+1\right)\right]^2\right\} = 6469^2\left\{\Gamma\left(\frac{2}{3{,}674}+1\right)-\left[\Gamma\left(\frac{1}{3{,}674}+1\right)\right]^2\right\}$ (9)	3125654 h^2

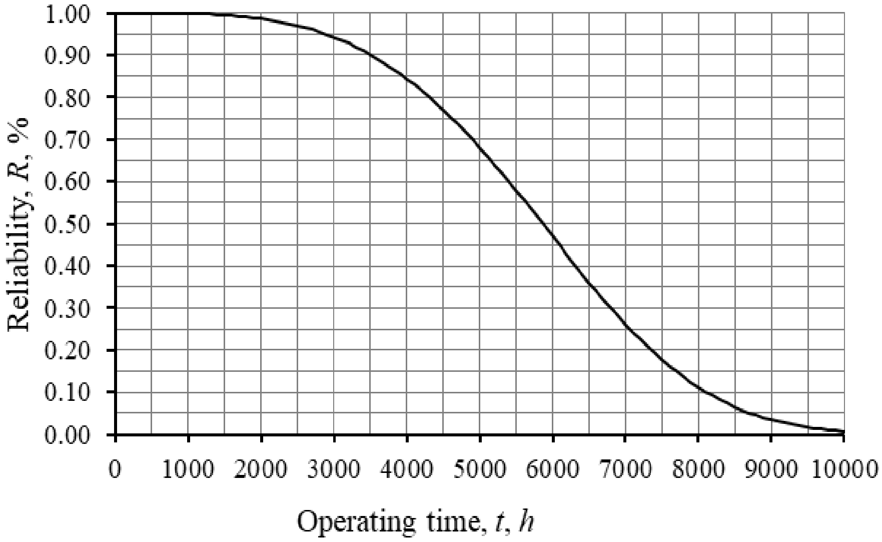

Fig. 3. $R_{B1}(t)$ function of the reliability of the EP 250/5 strip carpet

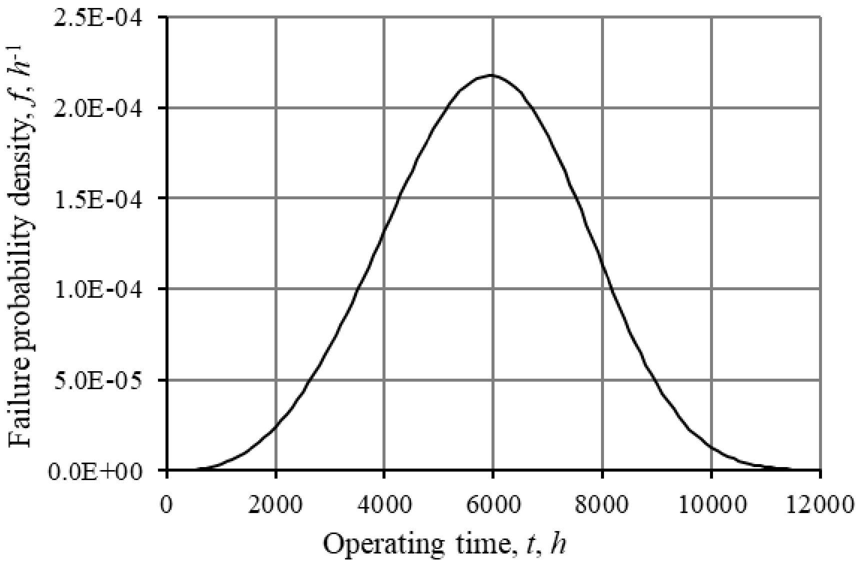

Fig. 4. Failure probability density function $f_{B1}(t)$

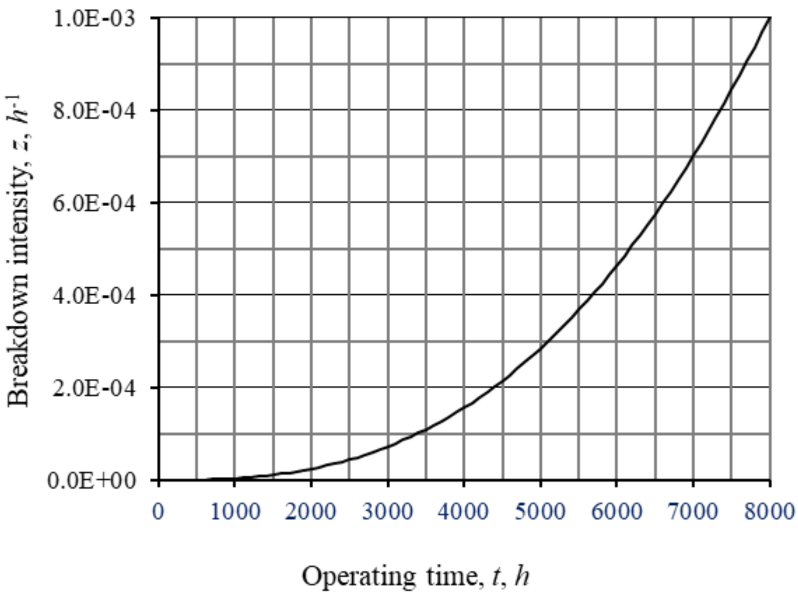

Fig. 5. The function zB1(t) of the breakdown intensity of the strip carpet

3. EVALUATION OF THE RELIABILITY INDICATORS OF THE BELT CONVEYOR EP 250/5 FOR THE B5S CONVEYOR [5]

3.1. Database [4]

Table 4. **The B5S transporter. Times of effective operation until decommissioning a tape drum EP 250/5**

Nr. crt., i	Name of the work	Installation date	Effective operating time, h
1	Inserting tape drum	26.09.2013	1800
2		30.08.2014	1850
3		29.07.2015	1594
4		21.04.2016	1684
5		09.02.2017	1372
6		04.10.2017	1768
7		12.07.2018	2532
8		26.06.2019	1569
9		16.01.2020	1575
10		27.08.2020	1904
11		14.05.2021	1757
12		08.12.2021	1366
13		18.05.2022	1806

The statistical series consists of n = 13 terms representing the operating times until the changeover tape carpet. The series, in actual hours of operation, is: 1366, 1372, 1569,1575, 1594, 1684, 1757, 1768, 1800, 1806, 1850, 1904, 2532.

3.2. The empirical defect distribution function, F̂(ti)

The empirical distribution function of the belt carpet failures, also called the experimental function, is determined with the estimator $\widehat{F}_i = \frac{i - 0,3}{n + 0,4}$. Its evolution is presented in table 5.

Table 5. **Transporter B5S. Empirical distribution function of times to carpet replacement of conveyor**

i	**t, h**	**$\widehat{F}(t_i)$**	**i**	**t, h**	**$\widehat{F}(t_i)$**	**i**	**t, h**	**$\widehat{F}(t_i)$**	**i**	**t, h**	**$\widehat{F}(t_i)$**
1	1366	0,052239	5	1594	0,350746	9	1800	0,649254	13	2532	0,947761
2	1372	0,126866	6	1684	0,425373	10	1806	0,723881			
3	1569	0,201493	7	1757	0,500000	11	1850	0,798507			
4	1575	0,276119	8	1768	0,574627	12	1904	0,873134			

3.3. Theoretical failure distribution function, failure function, F(t)

The theoretical defect distribution function that best characterizes the strip functionality is expressed by the triparametric Weibull distribution, $F(t) = 1 - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$, where β is the dimensionless parameter of form, η the real scale parameter, measured in hours, γ the initialization parameter, expressed in hours.

The distribution parameters are estimated by the method of moments.

The shape parameter β = 6.965 is obtained by solving Eq

$$\sqrt{\Gamma\left(\frac{2}{\beta}+1\right) - \left[\Gamma\left(\frac{1}{\beta}+1\right)\right]^2} - \frac{\sigma}{m} = 0 \tag{10}$$

In this relationship σ = STDEV (ti) = 293 hours is the standard deviation, or root mean square deviation of the times of operation of the tape drums, and m = AVERAGE (ti) = 1737 h is the average of the same operating times.

The real scale parameter η = 1857 h and the initialization parameter γ = 4.9E-06 h.

$$F(t) = 1 - e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} = 1 - \mathrm{e}^{-\left(\frac{\mathrm{t} - 4,9\mathrm{E}\text{-}06}{1857}\right)^{6,965}} \tag{11}$$

Applying the Kolmogorov-Smirnov distance concordance test to the triparametric Weibull distribution leads to the relationship,

$$\max_{1 \le i \le n}\left\{\left|F(t_i)\text{-}\widehat{F}(t_i)\right|, \left|F(t_i)\text{-}\widehat{F}(t_{i-1})\right|\right\} = 0,177364 < D_{\alpha,\,n} = D_{0,5\,,n} = 0,459212 \tag{12}$$

This relationship demonstrates that the triparametric Weibull distribution is validated with a confidence level of 99.5%, the risk α being only 0.5%.

It is specified that the following are also validated:

- the normal distribution, where the parameters mean m and standard deviation σ are estimated by the method of maximum likelihood;
- the biparametric Weibull distribution, with the shape parameter β and the real scale parameter η estimated by the method of least squares.

The triparametric Weibull distribution with the smallest dispersion value is adopted. Equally so can also use the normal distribution which has the same value of dispersion.

3.4. The main reliability indicators of the belt carpet EP 250/5

Table 6 and figures 6, 7 and 8 summarize the main reliability indicators for the belt carpet EP 250/5 from the B5S conveyor, and implicitly for the B5S pickup-deposit conveyor in assembly.

Table 6. **The main reliability indicators of the tape carpet with textile inserts EP 250/5 part of the B5S roller belt conveyor**

Nr. crt.	Name and symbol indicator	Calculation relation	Value, UM
1	The reliability function, RB5S(t)	$R_{B5S}(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} = e^{-\left(\frac{t+4{,}9E\text{-}06}{1857}\right)^{6,965}}$ (13)	Fig. 6
2	The probability density function of the time between failures, fB5S (t)	$f_{B5S}(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} = \frac{6{,}965}{1857}\left(\frac{t+4{,}9E\text{-}06}{1857}\right)^{5,965} e^{-\left(\frac{t+4{,}9E\text{-}06}{1857}\right)^{6,965}}$ (14)	Fig. 7
3	The breakdown intensity function, zB5S(t)	$z_{B5S}(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} = \frac{6{,}965}{1857}\left(\frac{t+4{,}9E\text{-}06}{1857}\right)^{5,965}$ (15)	Fig. 8
4	Mean time between failures, MTBFB1, E(T)B1	$E(T)_{B5S}=\gamma+\eta\cdot\Gamma\left(\frac{1}{\beta}+1\right)= -4{,}9E\text{-}6+1857\cdot\Gamma\left(\frac{1}{6{,}965}+1\right)$ (16)	1737 *h*
5	Median time between failures, t0.5;B5S, tmed;B5S	$t_{0,5;B5S}=\gamma+\eta\sqrt[\beta]{-\ln 0{,}5}= -4{,}9E\text{-}6+1857\cdot\sqrt[6,965]{-\ln 0{,}5}$ (17)	1762 *h*
6	Dispersion of time between failures, DB5S	$D_{B5S} = \eta^2\left\{\Gamma\left(\frac{2}{\beta}+1\right)-\left[\Gamma\left(\frac{1}{\beta}+1\right)\right]^2\right\} = 1857^2\left\{\Gamma\left(\frac{2}{6{,}965}+1\right)-\left[\Gamma\left(\frac{1}{6{,}965}+1\right)\right]^2\right\}$ (18)	85947 h^2

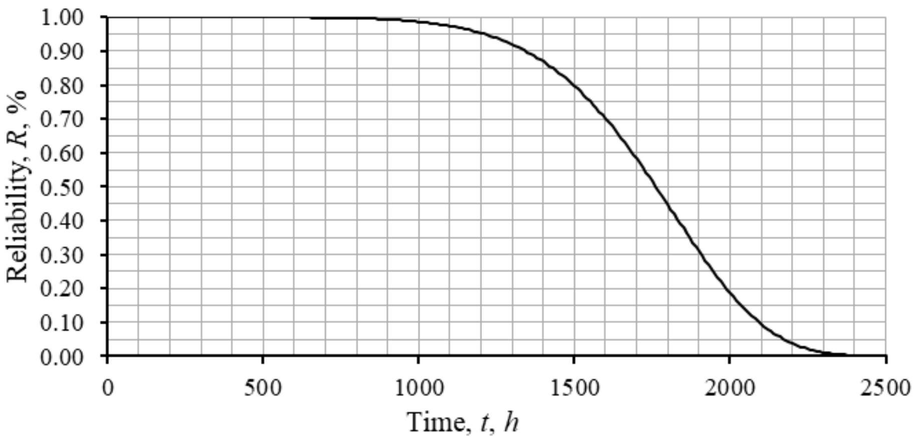

Fig. 6. *The* function $R_{B5S}(t)$ of the reliability of the strip carpet

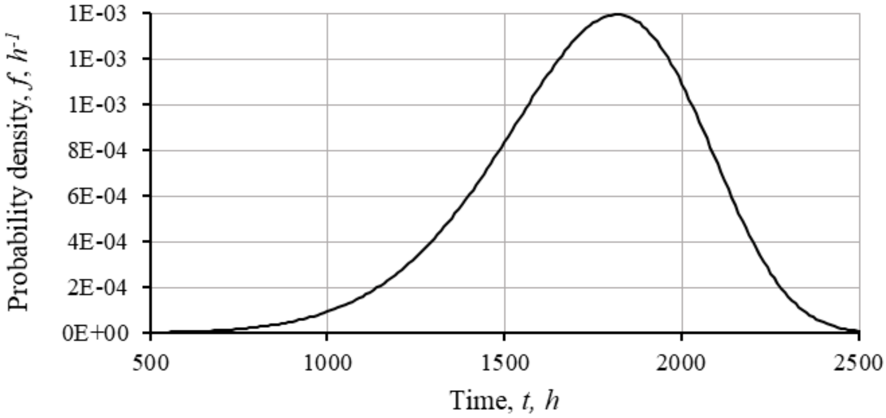

Fig. 7. Function $f_{B5S}(t)$ of the probability density of failures

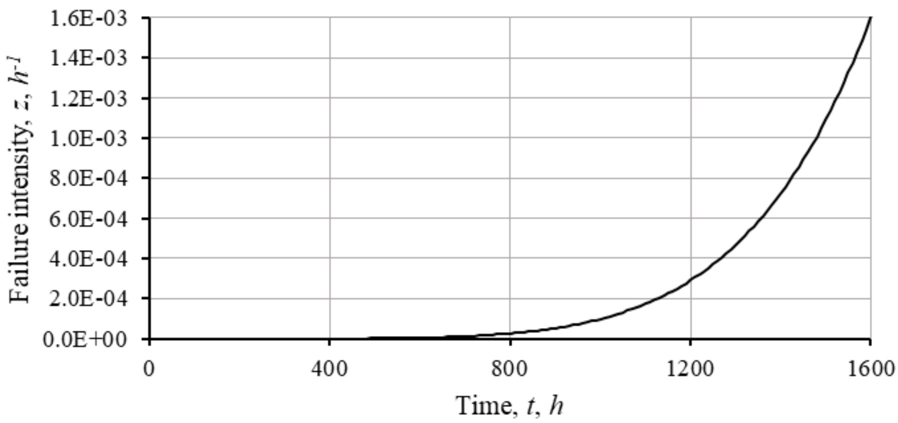

Fig. 8. Function z_{B5S} (t) of the failure intensity of the strip carpet

CONCLUSIONS

The database used for the evaluation of the reliability indicators is generous by highlighting the failure of the belt carpet over a period of 10 years, which increases the credibility of the results obtained. To model the functionality of the strip carpet with textile inserts EP 250/5 the distribution is used Weibull triparameter. The usefulness of this distribution in modeling the phenomena of wear and aging of materials is confirmed. The belt carpet EP 250/5 is a reliable product recommended for use in the conditions of the Roșia quarry Poieni.

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