sustainability

Article

Influence of Disinfectants on Airport Conveyor Belts

Katarína Draganová *, Karol Semrád, Monika Blišťanová, Tomáš Musil and Rastislav Jurč

Faculty of Aeronautics, Technical University of Košice, Rampová 7, 041 21 Košice, Slovakia; karol.semrad@tuke.sk (K.S.); monika.blistanova@tuke.sk (M.B.); tomas.musil@tuke.sk (T.M.); rastislav.jurc@student.tuke.sk (R.J.)
* Correspondence: katarina.draganova@tuke.sk; Tel.: +421-55-602-6153

Abstract: The coronavirus disease has influenced almost all of our everyday activities. Traveling and transportation have been influenced significantly and there is no doubt that air transportation has been restricted and therefore reduced considerably. It is predicted that the change back to pre-pandemic conditions will take several years, and so it is a reasonable assumption that disinfectants will be used more frequently for a long time. The presented article initially deals with the possible impacts of the pandemic on aircraft infrastructure—namely, on the influence of disinfectants on the rubber materials used, for example, in conveyor belts. The proposed methodology is based on the Weibull analysis for conveyor belt lifetime prediction regarding the impact of disinfectants. The Weibull distribution is a continuous probability distribution that can be applied as a theoretical model for statistical data processing. It was named after Weibull, who suggested shape, scale, and location parameters that made the distribution meaningful and useful. Currently, this distribution is applied in many areas, such as biology, economics, and hydrology. In engineering applications, it can be used for reliability and survival analysis. It is used mainly in cases where failure time is dependent on the operating hours, cycles, or age of the component. In the reliability area, it can be used, for example, to predict the lifetime or failure time of a component. To show the consequences of material changes due to the use of disinfectants, this article also presents a CAE (Computer Aided Engineering) analysis that was used for the evaluation of other hyperelastic material characteristics. This research is based on the results of experimental measurements, during which the influence of the types of disinfectant commonly used for the elimination of the coronavirus disease on airport conveyor belt rubber segments was tested. From the performed analysis, it was found that the influence of disinfectants on the material characteristics, including material hardness, elasticity, and static and dynamic loading, could be significant. Therefore, the probability of mechanical damage to the rubber part of the conveyor belt becomes higher, and time intervals for the maintenance or repair of airport conveyor belts should be considered.

Keywords: conveyor belt; disinfectant; Weibull distribution; hyperelastic material

Citation: Draganová, K.; Semrád, K.; Blišťanová, M.; Musil, T.; Jurč, R. Influence of Disinfectants on Airport Conveyor Belts. *Sustainability* **2021**, *13*, 10842. https://doi.org/10.3390/su131910842

Academic Editors: Jinjun Tang, Xinqiang Chen, Yongsheng Yang and Wenhui Zhang

Received: 13 September 2021
Accepted: 25 September 2021
Published: 29 September 2021

1. Introduction

The Weibull distribution is a continuous probability distribution named after Swedish mathematician Waloddi Weibull. He originally proposed the distribution as a model for materials' breaking strength but recognized the further potential of the distribution in his paper from 1951 [1]. Today, it is commonly used to assess product reliability and perform different kinds of reliability analysis [2] and modeling [3]. The Weibull distribution can fit a wide range of data from many different fields, including biology, medicine, economics, environmental science, and other kinds of science [4–6]. However, one of the most important application areas is engineering, where it is commonly used for the fatigue life prediction of different types of products, components, or elements [7–9].

The Weibull distribution can be also used in the transportation industry. For example, it can be used for the modelling of multi-objective stochastic transportation problems [10]. It can be used in rail transportation—for example, for the analysis of the longitudinal load of the wheels rolling along the rail [11]; in road transportation for the analysis of traffic losses [12], for the characterization of vibration levels [13], for the quality control of construction and maintenance processes of highway mechanical and electrical systems [14], or for the lifespan evaluation of traffic detectors for automated traffic recorders [15]; or to determine optimal flow distribution plans for mining, for urban electric vehicles, and for charging stations [16]. Air transportation is no exception. The Weibull distribution can be used in engineering to analyze causes of damage to aircraft components [17], as well as for demand forecasting—for example, when restoring air material [18] for helicopters. In the area of UAVs (Unmanned Aerial Vehicles), which are considered to be a prospective technology, it can be used, for example, for performance comparisons of wireless UAV systems [19].

Thanks to its versatility and relative simplicity, the Weibull distribution is also widely used in material engineering for the analysis of different kinds of materials, including metals and their alloys [8,9], ceramics [20], plastic materials [21,22], and asphalt mixtures [23]. Nowadays, research in the area of composite materials is very extensive, in connection with statistical predictions and probability models based on the Weibull distribution [24–26]. However, there are only a few studies that deal with rubber materials. This involves research focused on tires [27], or on the addition of rubber into mixtures, such as asphalt–rubber mixtures [28] or rubber–concrete mixtures [29].

Our research is focused on air transportation—more specifically, on conveyor belts manufactured from hyperelastic materials. Regarding belt conveyors, research related to the statistical prediction of models' design and development is focused on condition monitoring for airport baggage handling [30], on the material-handling equipment used in the operation process [31], on multi-component fault diagnosis [32], on the diagnostics of the residual service life of steel frames [33], on core failure detection [34], on decision making for predictive maintenance [35], on the investigation of rubber composite conveyor belts [36], and on related transient stress analyses [37]. The Weibull distribution, and its utilization related to belt conveyors, is usually focused on maintenance planning or used for predictive purposes [38].

In addition to the fact that this article deals with the much-discussed COVID-19 pandemic, where the Weibull distribution can be used, for example, for an impact analysis of COVID-19 [39] or for forecasts and predictions of future pandemics [40], it also offers a different view of conveyor belt operation in difficult operational conditions influenced by the increased application of disinfectants to the rubber parts of conveyor belts. This article presents the application of the Weibull distribution to the probability of the material hardening of conveyor belts after the application of disinfectants. The statistical analysis is based on the experimental results obtained from the material hardness measurement of conveyor belt samples exposed to different types of commonly used disinfectants.

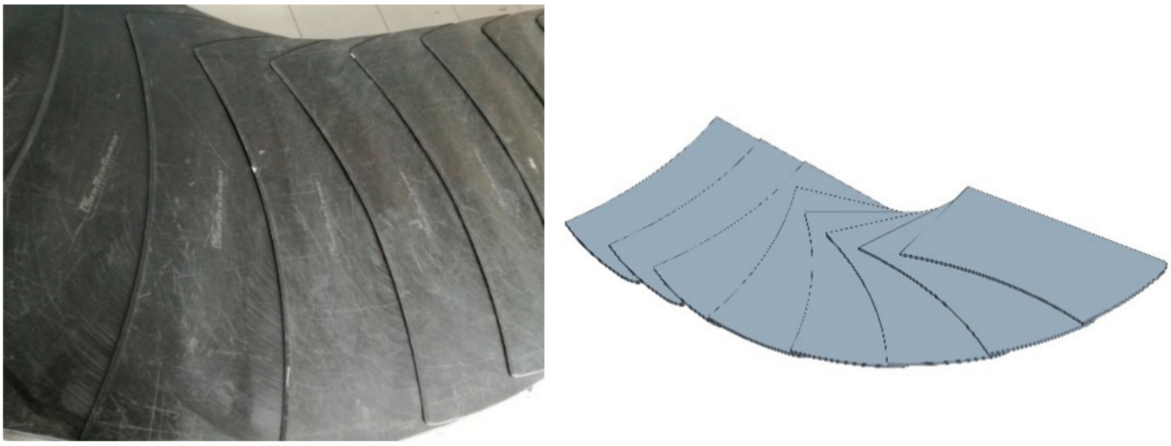
Furthermore, the experimental results of the mechanical tests created a basis for a simulation model of the rubber part of a conveyor belt, which served for the stress–strength analysis and the determination of the static and dynamic loading allowed after the utilization of the disinfectants. For better visualization, the concentration of the mechanical stresses is shown on the simulation model involving mechanical damage, which can be observed on the rubber parts of the conveyor belts in operation.

2. Materials and Methods

In the following section, the conveyor belt rubber material together with the disinfectants and their fundamental material and mechanical properties are described. The next part of the section involves the description of the experimental part of the performed research. In the last part of the section, the application of the Weibull distribution as a statistical approach to experimental data processing is presented.

2.1. Materials

Our experimental research was based on rubber samples from a conveyor belt and its corresponding CAD (Computer-Aided Design) model used at the Košice International Airport, as shown in Figure 1. For the experiments, samples that were in operation for 5 years were chosen due to the fact that anti-COVID-19 actions were applied to the existing airport infrastructure.



(**a**) (**b**)

Figure 1. The rubber part of the conveyor belt at Košice International Airport: (**a**) in operation; (**b**) CAD (Computer-Aided Design) model.

For further statistical analyses and simulations, the material characteristics of the rubber samples were obtained using the Zwick Roell Z030 and Bereiss HPE II testing devices.

The average results of the mechanical tests based on three measurements performed using the Zwick Roell Z030 were imported into the Creo Simulate software and can be seen in Figure 2. From the measured stress–strain curve, the material limits can be determined. In our case, the tensile yield stress used for further analyses was 6.7 MPa and the tensile ultimate stress was 7.6 MPa. Based on the experiments performed, from the material models available for the hyperelastic material analysis, the Neo-Hookean material model [41] with a constant $C10$ equal to 1.98877 MPa and a $D1$ equal to 0 MPa^{-1} was chosen as the most suitable.

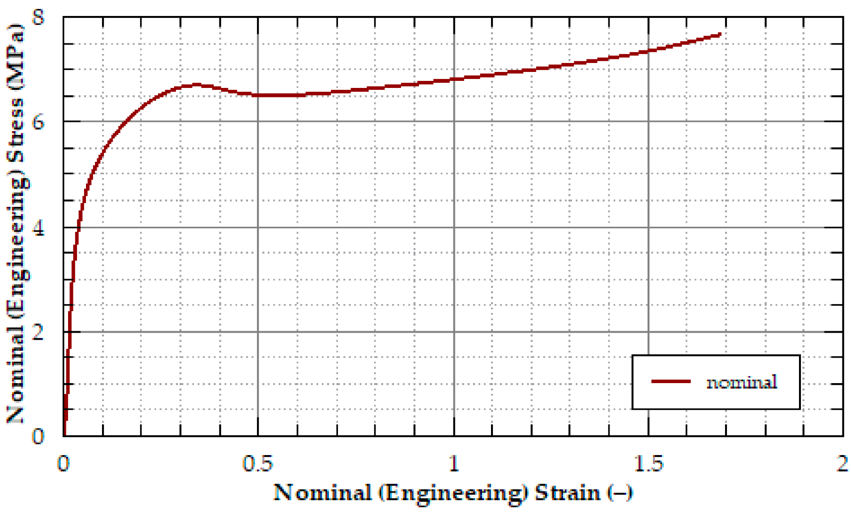


Figure 2. Stress–strain diagram.

The material hardness was determined according to ISO 868:2003: "Plastics and ebonite." Indentation hardness was determined by means of a durometer (Shore hardness) using the Shore A method for soft rubber materials with a minimum thickness of 4 mm. The thickness was verified for every sample at 3 points. In our case, the average thickness of the samples was 5.7 mm. The samples were placed into the working area of the Breiss HPE II digital hardness tester equipped with the Hardtest software. During the measurement, 5 testing points were placed at least 9 mm from the edge and at least 6 mm from other testing points.

The rubber samples were exposed to four kinds of commonly used disinfectants—ethanol (70%); Sanytol (involving dodecyl (dimethyl) ammonium chloride); Savo (involving sodium hypochlorite, 30%); and hydrogen peroxide—H_2O_2 (30%). During the experiments, contrary to recommendations [42], ten-times-higher concentrations were used due to the need to observe long-term effects in shorter time intervals.

2.2. Methods

The methodology was based on ISO 1817:2015: "Rubber, vulcanized or thermoplastic—Determination of the effect of liquids", which describes methods for evaluating the resistance of vulcanized and thermoplastic rubbers to the action of liquids by measuring the properties of the rubbers before and after immersion in test liquids. The main motivation of the research was that disinfectants can influence or change the material characteristics of rubber, and this can be revealed by the measurement and analysis of the stress–strain dependence and material hardness. Material characteristics were tested in compliance with the ISO 283:2015 standard, which deals with the test method for the determination of the full-thickness tensile strength of the type A test piece in the longitudinal direction and of the elongation of the reference force and breaking point of conveyor belts. As mentioned previously, the hardness was determined using the Shore method according to the ISO 868:2003 standard.

For the experiments, the material characteristics and hardness of the rubber samples were determined before the application of the disinfectants. These values were considered to be nominal values. The rubber samples were then exposed to the disinfectants (see Figure 3). The material characteristics and hardness were measured after one, two, three, and four weeks. After these experiments, the material characteristics and hardness were once again tested after a further six weeks. During this time, natural ageing with no disinfectant application was also tested. Before the tests, the samples were dried. The obtained data were processed in two ways—using the Weibull distribution and the Creo Simulate software.

Figure 3. Rubber conveyor belt samples exposed to the disinfectants.

2.3. Weibull Distribution

Weibull models are used to describe various phenomena, including the failure of components. They are widely used in reliability and survival analyses [43–45]. Nowadays, many types of modifications, extensions, and variations of the model are used [46–52].

In our case, the two-parameter version of the Weibull distribution was used. The relationship for the reliability (1) assuming the Weibull distribution is:

$$R(t) = e^{-\left(\frac{x}{\alpha}\right)^{\beta}} \tag{1}$$

where x, in our case, represents the hardness of the material; parameter α represents the characteristic life, which is a measure of the scale or spread in the distribution of data; and parameter β, which is a shape parameter, indicates whether the failure rate is increasing. Applying a linear regression, the Weibull parameter β can be determined directly from the slope of the line. The α parameter (2) has to be estimated as follows:

$$\alpha = e^{-\left(\frac{b}{\beta}\right)} \tag{2}$$

The Weibull distribution was chosen for the statistical analysis due to its versatility. Furthermore, it can be used for analyzing lifetimes with a very small number of samples. Thanks to this analysis, it is possible to forecast how the mechanical properties of the material will change based on the disinfectants applied, which can significantly influence the chosen material characteristics, especially if we consider the hyperelastic materials used on conveyor belts. In our case, the probability of a change in the material hardness when exposed to the four different types of conventionally used disinfectants in the specified period was analyzed.

From the results of these calculations, it is possible to create graphs that are very readable and offer an interpretation of the data. This is convenient for technical and operational aviation personnel, who can, thanks to the analysis results, create and implement plans for corrective actions and plan maintenance and repairs of belt conveyors.

3. Results

The Weibull analysis was used to determine the probability of a hardness change in the rubber samples exposed to the four different types of disinfectant. The hardness values measured after 4 weeks are summarized in Table 1. The nominal value of hardness before the application of the disinfectants was 97.3. As the measured values used for the further calculations are average values, for comparison the minimal measured values of the hardness are also presented.

Table 1. Hardness of the material after the application of disinfectants.

	Hardness (–)	**Min. Hardness (–)**
Savo	94.5	92.8
Sanytol	93.1	92.5
Ethanol	96	95.2
H_2O_2	97.2	95.8

The obtained results of the Weibull analysis can be seen in Figure 4. The obtained α and β distribution parameters are summarized in Table 2.

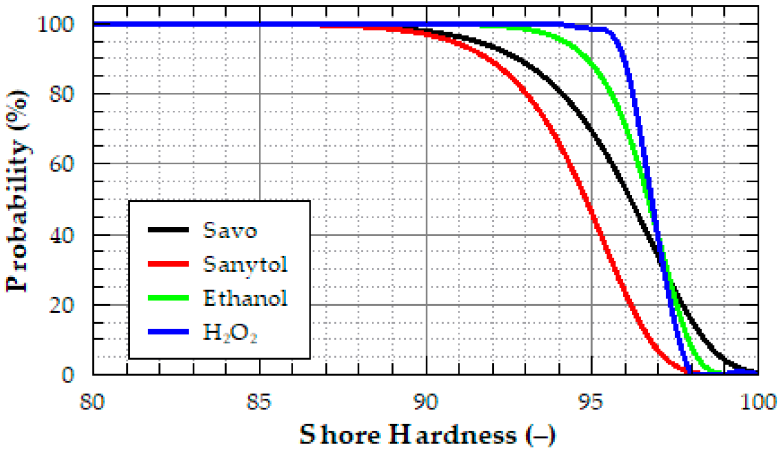


Figure 4. Probability of a hardness change after the application of disinfectants.

Table 2. Weibull distribution parameters.

	α (–)	β (–)
Savo	96.83	52.41
Sanytol	95.39	59.68
Ethanol	97.06	97.41
H_2O_2	97.01	201.77

In addition to hardness changes, changes in other mechanical properties were also observed. Based on the performed experiments, the stress–strain curves not only for the original, nominal sample but also for the samples exposed to the disinfectants were determined, as can be seen in Figure 5. From these curves, the material limits involving tensile ultimate stresses were obtained. These obtained material parameters were subsequently used for further analysis. The change in the tensile ultimate stress causes further changes in the related parameters, involving a failure index analyzed using the FEM (Finite Element Method) in the Creo Simulate software.

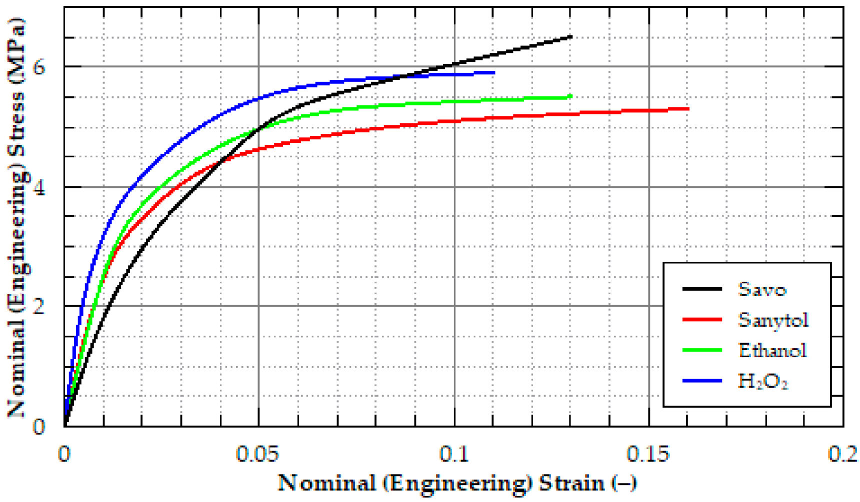


Figure 5. Stress–strain curves of the samples after the application of disinfectants.

The FEM model for the structural analysis with the mesh characteristics can be seen in Figure 6. For the analysis, a mechanical model involving 7256 tetra elements was used. In Figure 7, the same model with the clearly visualized boundary conditions and applied loads is shown. Related material characteristics can also be seen.

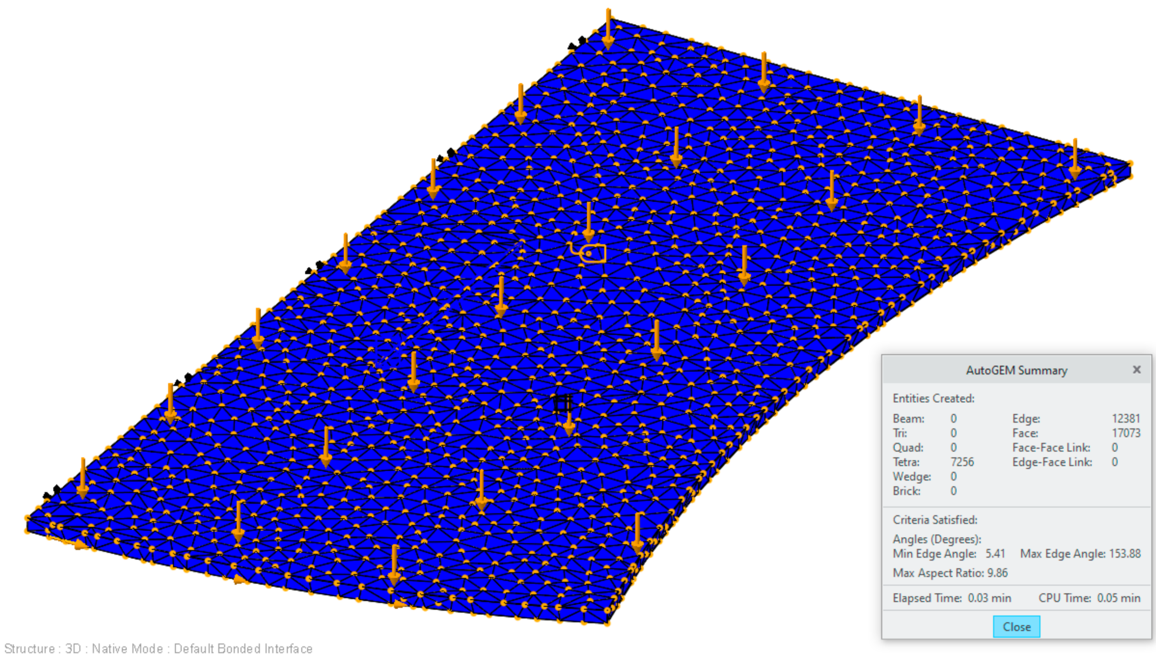


Figure 6. FEM (Finite Element Method) model of the conveyor belt with the mesh characteristics.

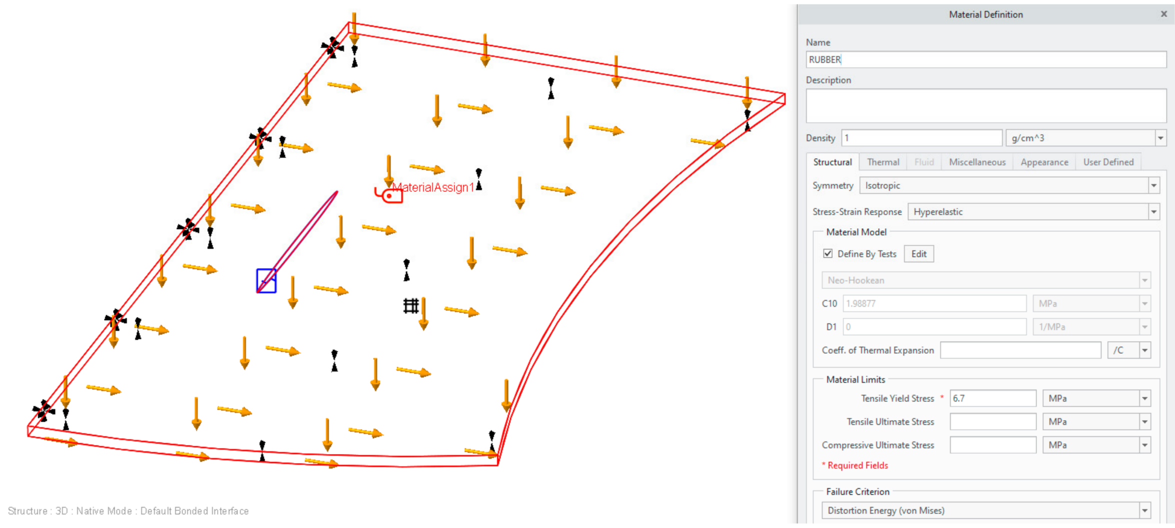


Figure 7. FEM model of the conveyor belt with the boundary conditions, applied loads, and related material characteristics.

The initial FEM model used for the CAE (Computer Aided Engineering) analysis can be seen in Figures 6 and 7. It was meshed using 7256 tetra elements. As mentioned previously, the disinfectants are usually applied to conveyor belts in operation. The model was based on the samples obtained from the conveyor belt shown in Figure 1. The sample includes a visible crack. Therefore, the FEM model also includes a crack with a length of 10 cm and a thickness of 2 mm placed 5 cm from the edge, corresponding to the visually observed crack. In Figure 8, the deformation of the conveyor belt rubber with a load of 1 N is shown. In this case, the calculated maximum displacement was 4.12×10^{-3} mm. For comparison, in addition to the deformed model, the initial model without deformations was also included in the final visualization of the analysis results. The failure index calculated during the analysis was 0.0001338. The simulation results can be seen in Figure 9 and in detail in Figure 10. For better visualization, contours instead of continuous tones were used to show the simulation results.

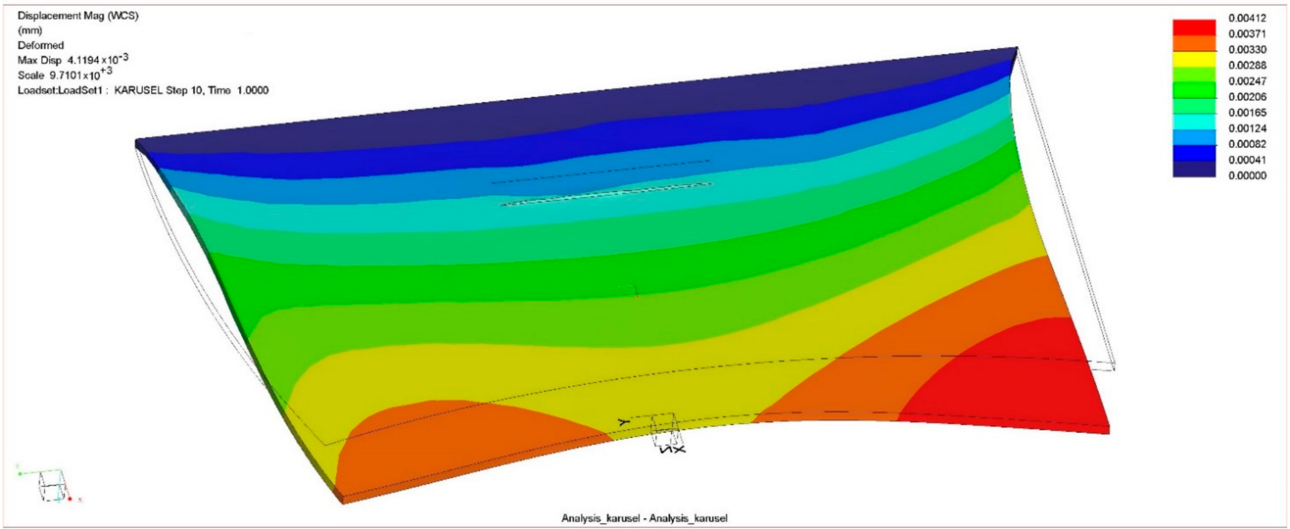


Figure 8. Deformation of the rubber part of the conveyor belt before the application of the disinfectants.

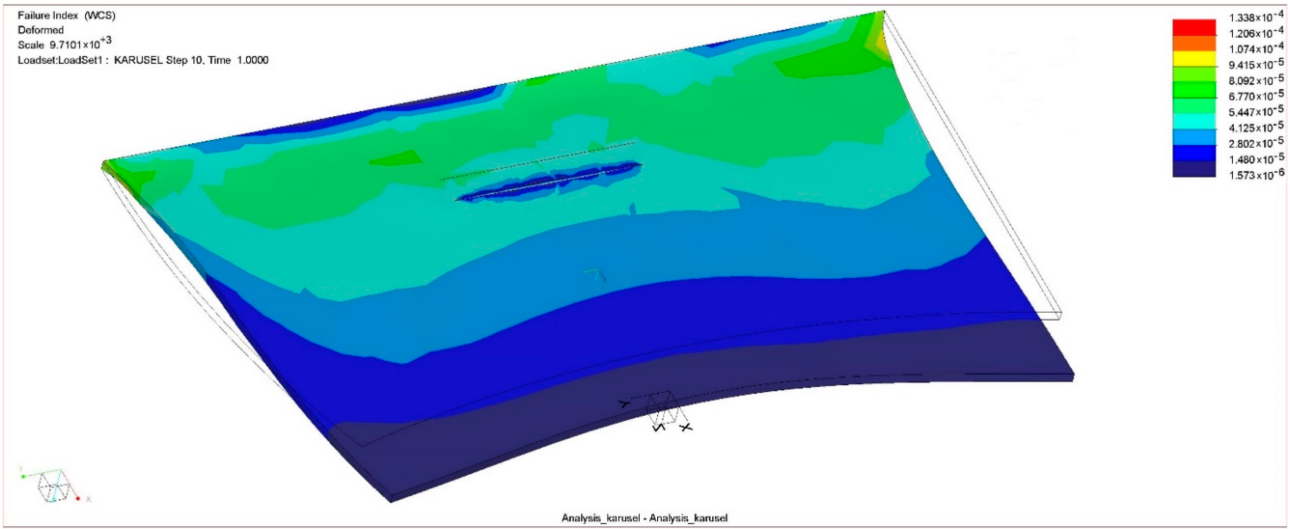


Figure 9. Failure index of the rubber part of the conveyor belt before the application of the disinfectants.

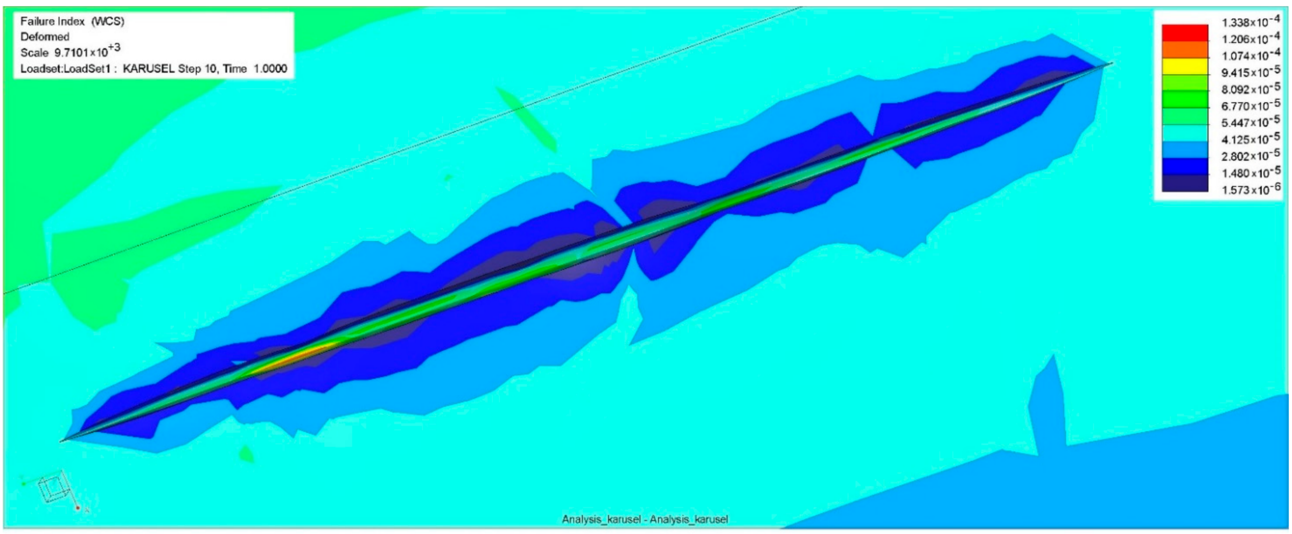


Figure 10. Detail of the failure index of the rubber part of the conveyor belt before the application of the disinfectants.

From the obtained simulation results, the calculation of the allowed static load L_s (3) was performed:

$$L_s = 1 \ / \ FI \tag{3}$$

where *FI* is the calculated failure index. A failure index is used to determine whether a material has failed because of excessive stress levels, which might be caused by an applied load or an enforced displacement constraint. In our case, the determined static load for the nominal sample was 7473.84 N, which corresponds to the value of 747 kg.

As conveyor belts are often exposed also to dynamic impact, in addition to the allowed static load, the allowed dynamic loads L_d (4) were also calculated:

$$L_d = L_s \ / \ c \tag{4}$$

where *c* is the dynamic coefficient (5) calculated as:

$$c = 1 + \sqrt{1 + \frac{2 \times H}{y_{st}}} \tag{5}$$

where y_{st} is the deformation caused by the static load and *H* is the height from which the object falls onto the conveyor belt. In our case, the simulations were performed for a height of zero, thus the dynamic coefficient is equal to 2 and the determined dynamic load of the nominal sample was 373.5 kg.

The measured mechanical properties, represented by the tensile ultimate stress determined from the measurements, related calculated values represented by the failure index, and static and dynamic loads for the nominal sample and for the samples exposed to the disinfectants, are summarized in Table 3.

Table 3. FEM (Finite Element Method) analysis results before and after the application of disinfectants.

	Tensile Ultimate Stress (MPa)	Failure Index (–)	Static Load (kg)	Dynamic Load (kg)
Nominal	7.6	0.0001338	747.0	373.5
Ethanol	5.5	0.0008846	113.0	56.5
Sanytol	5.3	0.0009180	108.9	54.4
Savo	6.5	0.0007485	133.6	66.8
H_2O_2	5.9	0.0008246	121.2	60.6

4. Discussion

The main goal of the presented work was to statistically evaluate the probability of a change in the hardness of the conveyor belt rubber segments commonly used at airports following the application of disinfectants. The changes in the mechanical properties were experimentally measured and the stress–strain dependence and material hardness were determined.

From the experimental results obtained, it is obvious that one of the most influenced characteristics was material hardness. This is the reason why a statistical data analysis using the Weibull distribution was applied to evaluate the probability of a hardness change after the application of disinfectants. From the analysis, it can be seen that the material hardness decreased most significantly in the case of the application of H_2O_2. On the contrary, in the case of the Sanytol, the material hardness decreases the most slowly and the decrease is significantly lower in comparison to the other tested disinfectants. It can be also seen that, in the case of the other three tested disinfectants (H_2O_2, ethanol, and Savo), the material hardness achieves a value of 97.3 with a 30% probability. This value is very important due to the fact that this material hardness corresponds to the nominal material hardness measured before the application of disinfectants. However, the material hardness of the Sanytol is, with the same probability, 95.7. From the Weibull analysis, it can also be seen that the material hardness decreases to a value of 92 in the case of H_2O_2 application. For ethanol, the material hardness decreases to a value of 87, and for Savo and Sanytol it can be expected that the value of the material hardness will be 80.

From this part of the research, it can be concluded that when material hardness decreases, the probability of mechanical damage increases. That is the reason why, in addition to the evaluation of the material hardness, another set of experimental measurements was performed. From these experiments, the stress–strain dependences were determined and visualized using the Creo Simulate software.

From the simulation results, the failure index was evaluated. A failure index determines whether a material has failed under given loading conditions. If the failure index is less than 1, the material has not failed. If it is equal to or greater than 1, the material has failed. In our case, the material characteristics of the hyperelastic material were determined experimentally and a load of 1 N was used for the simulation. Subsequently, the allowed static and dynamic loadings of the conveyor belt, after the application of four different types of disinfectant on the rubber segments of the conveyor belt, were calculated. From the results summarized in Table 3, it can be seen that the hyperelastic material loses elasticity and, therefore, the allowed static and dynamic load decreases significantly. The deviation from the nominal value was, on average for the four applied disinfectants, 84%, which represents a significant change in the allowed static and dynamic loading. As it is generally known that airport conveyor belts are in operation continuously, not only under static loading but also dynamic loading, such as baggage falling onto the rubber segments of conveyor belts, it is obvious that in the case of the application of disinfectants, mechanical damage can occur in a significantly shorter time interval. This is the reason why the maintenance and possible repair of the rubber segments of airport conveyor belts should, during the pandemic, be scheduled to take place after shortened time intervals. However, it should be mentioned that, during these experiments, higher concentrations of disinfectant were applied.

Due to the significantly increased probability of mechanical damage to the rubber material, which was proven by the measurements of the material hardness of the rubber exposed to the disinfectants, the simulation model also included mechanical damage, which can be visually observed on the airport conveyor belts in operation. This type of damage is usually caused by the dynamic impact of baggage being thrown onto conveyor belts. Thanks to the simulation of the mechanical damage, it can be clearly seen how the mechanical stresses are concentrated in the proximity of this damage. If we consider that rubber exposed to disinfectant loses its hardness and elasticity and is thus more susceptible to mechanical damage, and that, due to the application of disinfectants, the allowed static and dynamic loading decreases significantly, the overall probability of it being necessary to carry out conveyor belt maintenance or repair increases considerably.

However, various types of rubber materials are used in conveyor belts, as well as many different types of disinfectant. Therefore, the goal of this article was not to precisely define time intervals for maintenance or repairs, but to point out that the hyperelastic materials commonly used not only for conveyor belts but also, for example, for floors, seats, handles, etc., can be sensitive to disinfectants and worn out much more quickly. However, as can be seen from Table 1, where the lowest impact can be observed for the application of H_2O_2 for the disinfection of this type of rubber material, the damage can be mitigated by applying the most convenient disinfectant.

The other goal of this article was to show the consequences of the utilization of disinfectants for one specific sample of the rubber part of a conveyor belt. The loss of elasticity leads to smaller static and dynamic loads being allowed, which can lead to damage to hyperelastic materials, mainly in areas where there are small cracks, as these areas are where mechanical stresses are concentrated. It is probable that these areas will become damaged and that it will be necessary to replace them.

5. Conclusions

The COVID-19 pandemic has had a dramatic impact on air transportation. The resulting prevention methods used and anti-pandemic restrictions and recommendations in place involve the utilization of disinfectants, which can help to restrict the rapid spread of the virus at airports. The influence of different kinds of disinfectants has been deeply studied regarding human health. However, the goal of this article was to prove that disinfectants can also have a significant influence on aircraft infrastructure and equipment. In our case, the influence of the selected commonly used disinfectants on airport conveyor belts was studied and analyzed.

For the experimental part of this research, samples from the rubber parts of airport conveyor belts were used. The mechanical tests, including stress–strain and material hardness determination, were performed before and after the application of high concentrations of disinfectants in one-week intervals for four weeks, and then after the next six weeks of natural aging. The obtained measurement results for the material hardness were subsequently processed using the Weibull distribution. From these results, it can be concluded that every type of disinfectant has a significant influence on the material hardness. With the decreasing value of material hardness, the elasticity of the material is also decreased, leading to a significant influence on the allowed static and dynamic loading of the rubber parts of airport conveyor belts. Considering the common dynamic impacts caused by baggage falling onto conveyor belts, the probability of the occurrence of mechanical damage is higher. Therefore, during the COVID-19 pandemic and the related utilization of disinfectants, shortening the maintenance and repair intervals of airport conveyor belts should be considered.

Author Contributions: Conceptualization, K.D. and K.S.; methodology, K.D., K.S. and M.B.; validation, M.B., T.M. and R.J.; formal analysis, M.B. and R.J.; data curation, T.M.; writing—original draft preparation, K.D., K.S. and M.B.; writing—review and editing, K.D.; visualization, K.D. and K.S.; project administration, K.S.; funding acquisition, K.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Slovak Research and Development Agency, grant number APVV-18-0248 and grant number APVV-17-0184 and the Research Agency, ITMS code number 313011T557.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Weibull, W. A Statistical Distribution Function of Wide Applicability. *J. Appl. Mech.* **1951**, *18*, 293–297. [CrossRef]
2. Zhang, C.W. Weibull parameter estimation and reliability analysis with zero-failure data from high-quality products. *Reliab. Eng. Syst. Saf.* **2021**, *207*, 107321. [CrossRef]
3. Thanh Thach, T.; Briš, R. An additive Chen-Weibull distribution and its applications in reliability modeling. *Qual. Reliab. Eng. Int.* **2021**, *37*, 352–373. [CrossRef]
4. Kam, O.M.; Noël, S.; Ramenah, H.; Kasser, P.; Tanougast, C. Comparative Weibull distribution methods for reliable global solar irradiance assessment in France areas. *Renew Energ.* **2021**, *165*, 194–210. [CrossRef]
5. Silahli, B.; Dingec, K.D.; Cifter, A.; Aydin, N. Portfolio value-at-risk with two-sided Weibull distribution: Evidence from cryptocurrency markets. *Financ. Res. Lett.* **2021**, *38*, 101425. [CrossRef]
6. Alshenawy, R.; Al-Alwan, A.; Almetwally, E.M.; Afify, A.Z.; Almongy, H.M. Progressive type-ii censoring schemes of extended odd weibull exponential distribution with applications in medicine and engineering. *Mathematics* **2020**, *8*, 1679. [CrossRef]
7. Strzelecki, P. Determination of fatigue life for low probability of failure for different stress levels using 3-parameter Weibull distribution. *Int. J. Fatigue* **2021**, *145*, 106080. [CrossRef]
8. Barraza-Contreras, J.M.; Piña-Monarrez, M.R.; Molina, A. Fatigue-life prediction of mechanical element by using the Weibull distribution. *Appl. Sci. Basel* **2020**, *10*, 6384. [CrossRef]
9. Wang, Y.; Chen, Z.; Zhang, Y.; Li, X.; Li, Z. Remaining useful life prediction of rolling bearings based on the three-parameter Weibull distribution proportional hazards model. *Insight Non-Destr. Test. Cond. Monit.* **2021**, *62*, 710–718. [CrossRef]
10. Abebaw Gessesse, A.; Mishra, R. Genetic Algorithm-Based Fuzzy Programming Method for Multi-objective Stochastic Transportation Problem Involving Three-Parameter Weibull Distribution. *Adv. Intell. Syst.* **2021**, *1170*, 155–167. [CrossRef]

11. Franchuk, V.P.; Ziborov, K.A.; Krivda, V.V.; Fedoriachenko, S.O. On wheel rolling along the rail regime with longitudinal load. *Nauk. Visnyk Natsionalnoho Hirnychoho Universytetu* **2017**, *3*, 62–67.
12. Milewska, A.; żukowska, J. An Attempt of Apply the Weibull Distribution in Road Traffic Losses Analysis. *J. Konbin* **2008**, *7*, 131–143. [CrossRef]
13. Rouillard, V.; Lamb, M.J. Using the Weibull distribution to characterise road transport vibration levels. *Packag. Technol. Sci.* **2020**, *33*, 255–266. [CrossRef]
14. Liwei, Z.; Liqing, W.; Jianping, L. Quality Control in Construction and Maintenance Process of Highway Mechanical and Electrical System Based on Weibull Distribution Model. *IOP C Ser. Earth Environ.* **2020**, *565*, 012027. [CrossRef]
15. Jung, Y.S.; Oh, J. Lifespan evaluation of traffic detector for Automated traffic recorders based on Weibull distribution. *J. Transp. Eng.* **2017**, *143*, 05017006. [CrossRef]
16. Kravets, V.; Ziborov, K.; Bas, K.; Fedoriachenko, S. Combined method for determining the optimal flow distribution plan for mining, urban electric vehicles and for charging stations. *E3S Web Conf.* **2019**, *123*, 01029. [CrossRef]
17. Jamaludin; Sumarno. Analysis of Causes Damage in Flight Compartment Windows Due to Heating System Failure in Boeing 737–800 Airport Using Weibull Analysis Distribution. *J. Phys. Conf. Ser.* **2020**, *147*, 052038. [CrossRef]
18. Niu, P.; Wang, Z.; Liu, S.; Jia, K. Demand Forecast of Restoring Air Material of Helicopter Based on NHPP and Weibull Model. *J. Phys. Conf. Ser.* **2020**, *1676*, 012089. [CrossRef]
19. Gupta, M.; Anandpushparaj, J.; Muthuchidambaranathan, P.; Jayakody, D.N.K. Outage Performance Comparison of Dual-Hop Half/Full Duplex Wireless UAV System over Weibull Fading Channel. In Proceedings of the 2020 International Conference on Wireless Communications Signal Processing and Networking, Chennai, India, 4–6 August 2020; pp. 177–181. [CrossRef]
20. Lei, W.-S.; Yu, Z.; Zhang, P.; Qian, G. Standardized Weibull statistics of ceramic strength. *Ceram. Int.* **2021**, *47*, 4972–4993. [CrossRef]
21. Boiko, Y.M. Weibull statistics of the lap-shear strength of a symmetric interface of amorphous poly (ethylene terephthalate). *Polym. Bull.* **2020**, *77*, 6377–6390. [CrossRef]
22. Berk, L.A.; Hallock, J.N. Predicting near-ground vortex lifetimes using weibull density functions. In Proceedings of the Collection of Technical Papers—45th AIAA Aerospace Sciences Meeting, Reno, Nevada, 8–11 January 2007; Volume 18, pp. 12746–12759.
23. Ashfaq, F.; Hafeez, I.; Hussan, S. Developing Non-Linear Relationship among Factors Affecting the Rutting Susceptibility of Asphalt Mixtures Using Two Parameter Weibull Distribution. *IOP C Ser. Mat. Sci.* **2020**, *899*, 012017. [CrossRef]
24. Attukur Nandagopal, R.; Narasimalu, S.; Chai, G.B. Study of statistically significant strength degradation of hygrothermal aged CFRP and its weibull analysis. *Compos. Commun.* **2021**, *23*, 100566. [CrossRef]
25. Belhadj, B.; Abdelkader, L.; Chateauneuf, A. Weibull probabilistic model of moisture concentration build up in a fiber graphite/epoxy polymer composite under varying hydrothermal conditions. *Period. Polytech. Mech.* **2021**, *65*, 27–38. [CrossRef]
26. Mukherjee, T.; Pati, B.; Senapati, D. Performance Evaluation of Composite Fading Channels Using q-Weibull Distribution. *Adv. Intell. Syst.* **2021**, *1198*, 317–324. [CrossRef]
27. Chiang, Y.J.; Shih, C.D.; Lin, C.C.; Tseng, Y.Y. Examination of tyre rubber cure by Weibull distribution functions. *Int. J. Mater. Prod. Tec.* **2003**, *20*, 210–219. [CrossRef]
28. Venudharan, V.; Biligiri, K.P. Rutting performance of asphalt-rubber gap-graded mixtures: Evaluation through statistical and reliability approaches. *Road Mater. Pavement* **2020**, *21*, S2–S18. [CrossRef]
29. Ming, P.; Lu, J.; Cai, X.; Liu, M.; Chen, X. Analysis of the Crack Evolution Process in Crumb Rubber Concrete Based on Acoustic Emission Technology. *KSCE J. Civ. Eng.* **2020**, *24*, 2088–2098. [CrossRef]
30. Koenig, F.; Found, P.A.; Kumar, M. Condition monitoring for airport baggage handling in the era of industry 4.0. *J. Qual. Maint. Eng.* **2019**, *25*, 435–451. [CrossRef]
31. Marasova, D.; Saderova, J.; Ambrisko, L. Simulation of the Use of the Material Handling Equipment in the Operation Process. *Open Eng.* **2020**, *10*, 216–223. [CrossRef]
32. Ravikumar, S.; Kanagasabapathy, H.; Muralidharan, V. Multi-Component Fault Diagnosis of Self Aligning Troughing Roller (SATR) in Belt Conveyor System using Decision Tree—A Statistical Approach. *FME Trans.* **2020**, *48*, 364–371. [CrossRef]
33. Marasová, D.; Cehlár, M.; Kolman, J. Diagnostics of the residual service life of steel frames of large-scale excavators. *Int. Multi. Sci. Geoco.* **2019**, *19*, 255–262. [CrossRef]
34. Blazej, R.; Jurdziak, L.; Kirjanów, A.; Kozlowski, T. Random Deterioration Process of Conveyor Belt Evaluated by Statistical Analysis of Core Failures Detected Along Belt Axis and Elapsed Time. *IOP C Ser. Earth Environ.* **2017**, *95*, 042046. [CrossRef]
35. Liu, X.W.; He, D.J.; Lodewijks, G.; Pang, Y.S.; Mei, J. Integrated decision making for predictive maintenance of belt conveyor systems. *Reliab. Eng. Syst. Saf.* **2019**, *188*, 347–351. [CrossRef]
36. Kessentinia, R.; Klinkova, O.; Tawfiq, I.; Haddar, M. Theoretical and Experimental Investigation of Bonded Patch Repairs of a Rubber Reinforced Composite Conveyor Belt. *Polymers* **2021**, *13*, 1710. [CrossRef]
37. Kessentinia, R.; Klinkova, O.; Tawfiq, I.; Haddar, M. Transient hygro-thermo-mechanical stresses analysis in multi-layers bonded structure with coupled bidirectional model. *Int. J. Mech. Sci.* **2019**, *150*, 188–201. [CrossRef]
38. Semrád, K.; Draganová, K.; Koščák, P.; Cernan, J. Statistical prediction models of impact damage of airport conveyor belts. *Transp. Res. Proc.* **2020**, *51*, 11–19. [CrossRef]
39. Rahman, S.M.M.; Kim, J.; Laratte, B. Disruption in Circularity? Impact analysis of COVID-19 on ship recycling using Weibull tonnage estimation and scenario analysis method. *Resour. Conserv. Recycl.* **2021**, *164*, 105139. [CrossRef]

40. Moreau, V.H. Forecast predictions for the COVID-19 pandemic in Brazil by statistical modeling using the Weibull distribution for daily new cases and deaths. *Braz. J. Microbiol.* **2020**, *51*, 1109–1115. [CrossRef]
41. Draganova, K.; Semrad, K.; Fozo, L.; Spodniak, M.; Jurc, R. Methodology for Structural Analysis of Hyperelastic Materials with Embedded Magnetic Microwires. *Metalurgija* **2020**, *59*, 389–392.
42. WHO. *Guide to Hybiene and Sanitation in Aviation*, 3rd ed; WHO: Geneva, Switzerland, 2009; ISBN 978-92-4-154777-2.
43. Guo, S.; Wang, X.; Liu, Y.; Zhu, X.; Zhai, Y. A comparison study of three types of parameter estimation methods on weibull model. *Adv. Intell. Syst.* **2021**, *1244*, 706–711. [CrossRef]
44. Ishaq, A.I.; Abiodun, A.A. The Maxwell–Weibull Distribution in Modeling Lifetime Datasets. *Ann. Data Sci.* **2020**, *7*, 639–662. [CrossRef]
45. Dorner, W. Using Microsoft Excel for Weibull Analysis. *Qual. Dig. Mag.* **1999**, 23237. Available online: http://www.qualitydigest.com/jan99/html/body_weibull.html (accessed on 3 February 2021).
46. Sumair, M.; Aized, T.; Gardezi, S.A.R.; Rehman, S.U.U.; Rehman, S.M.S. A novel method developed to estimate Weibull parameters. *Energy Rep.* **2020**, *6*, 1715–1733. [CrossRef]
47. Saboori, H.; Barmalzan, G.; Ayat, S.M. Generalized Modified Inverse Weibull Distribution: Its Properties and Applications. *Sankhya B* **2020**, *82*, 247–269. [CrossRef]
48. Hongxiang, L.; Shan, F.P.; Baofeng, S. A comparative study of modified Weibull distributions in proportional hazards models. *AIP Conf. Proc.* **2020**, *2266*, 090011. [CrossRef]
49. Nassar, M.; Afify, A.Z.; Shakhatreh, M.K.; Dey, S. On a new extension of Weibull distribution: Properties, estimation, and applications to one and two causes of failures. *Qual. Reliab. Eng. Int.* **2020**, *36*, 2019–2043. [CrossRef]
50. Jurić, V.; Kozubowski, T.J.; Perman, M. An asymmetric multivariate weibull distribution. *Commun. Stat. Theory* **2020**, *49*, 4394–4412. [CrossRef]
51. Marshall, A.W.; Olkin, I. A new method for adding a parameter to a family of distributions with application to the exponential and Weibull families. *Biometrika* **1997**, *84*, 641–652. [CrossRef]
52. Lai, C.D.; Xie, M.; Murthy, D.N.P. A modified Weibull distribution. *IEEE T Reliab.* **2003**, *52*, 33–37. [CrossRef]