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High-speed tensile testing of extruded PC based polymers for cable ducts

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Abstract. Previous tensile tests at 50, 100 and 400 mm/min using standard polycarbonate/ acrylonitrile butadiene styrene (PC/ABS) material qualities have led to the suspicion that strain at break decreases with increasing test speed. Here, the plastic deformation component is regarded as the main burr cause. Thus, higher process speeds during punching would lead to less burr formation. This thesis was proven by high-speed tensile tests with a self-developed test rig operating at a test speed of 36.000 mm/min. Both, pure standard materials, provided by a polymer granules supplier, and customized materials were investigated. The customized materials contain unknown additives generally used in industry, e.g. fillers. All samples were taken laterally from in-situ cable ducts. The remaining plastic strain was introduced as material parameter to compare the results of high-speed and conventional tensile tests. The investigations show that the remaining plastic strain which is understood as the major burr cause decreases with increasing test speed. Furthermore, the mean values of the remaining plastic strain of the individual materials converge when exposed to higher test speeds. This leads to the thesis that one tool configuration can be used for different polycarbonate (PC) based materials presumed the process speed is adjusted correctly.

1. Introduction

The formation of burrs and film during punching of polycarbonate acrylonitrile-butadiene-styrene (PC/ABS) in the procedure of cable duct manufacturing decreases the overall quality of the final product and therefore has to be suppressed. In detail, burr and film formation on the cut-outs of a cable duct can cause injury to both, workers and cables [1]. Moreover, the operational reliability of the electrical system is put at risk. With no adequate solution for this problem up to now an additional process step for deburring raises the product price.

PC/ABS is used in cable duct production because the standard material polyvinyl chloride (PVC) releases Cl^--ions when exposed to higher temperatures of approx. 210 °C and higher. These Cl^--ions can combine with free H^+-ions to form the hydrochloric acid HCl [2]. In addition, for some applications e.g. rail vehicles, compliance to the international UL94 standard for flammability of plastic materials is required. PC/ABS materials can fulfill this requirement with the best rating "v-0" [1,3].

Most studies focus on optimizing and analyzing the material properties of PC/ABS by varying the mixing ratio of PC to ABS, the butadiene content in the ABS, the process parameters while extruding and blending and optionally used additives [4-8].

In a first step, basic mechanical properties of the material have been investigated (tensile, hardness and impact testing [9]). Especially data from tensile tests according to DIN EN ISO 527 were of interest. In-situ PC/ABS samples taken from extruded cable duct covers were examined. The mean value as well as standard deviation of the strain at break decreases with increasing strain rate (figure 1). The results are currently based on materials provided by a polymer granules supplier. During the production of cable ducts, however, further additives such as limestone are added, resulting in customized materials with modified properties. The material properties, mixing ratios or additives used in these materials remain company property of the respective manufacturers.

Therefore, the results of the tensile tests still have to be verified for customized materials. A second drawback of the previous results are the strain rates applied being too low by a factor of 90 to 720. The tests were carried out at 50, 100 and 400 mm/min. The punching process, however, operates at 36.000 mm/min. Those strain rates cannot be tested using conventional tensile testing machines. Therefore, a new experimental setup for high-speed tensile tests was designed and successfully applied.

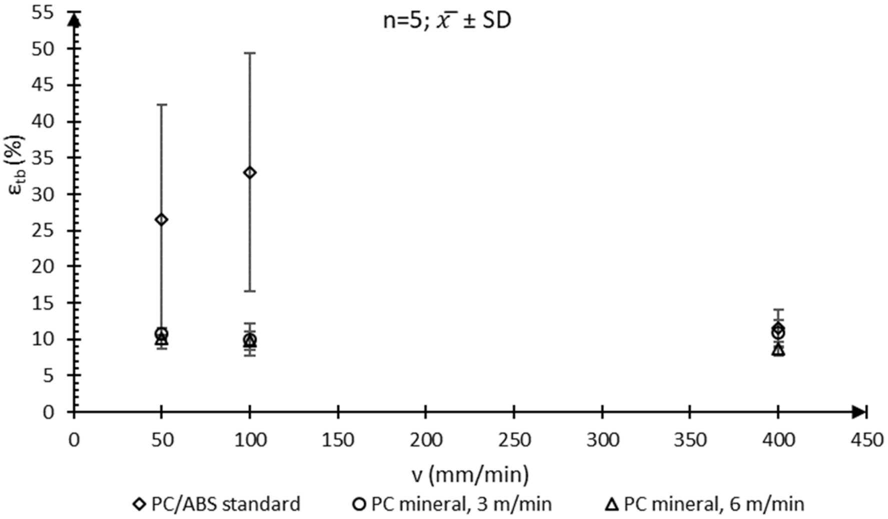

Figure 1. Strain at break derived from tensile testing as a function of speed during testing [9]

2. Materials and Methods

2.1. Materials

Six different qualities of flame retardant polycarbonate based materials for cable ducts were delivered as extruded cable duct covers (figure 2).

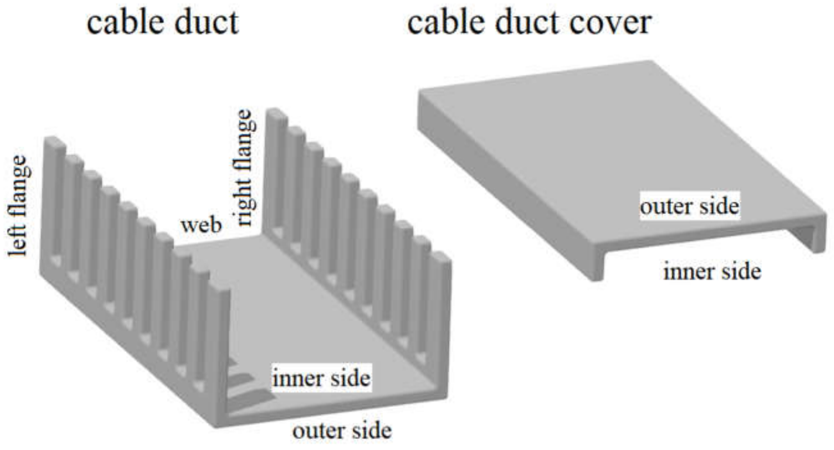

Figure 2. Cable duct and corresponding cover [9]

One specified as standard flame retardant PC/ABS and one as mineral reinforced flame retardant PC were provided by a polymer granules supplier. In addition, four flame retardant PC/ABS customized qualities were purchased from four different cable duct producers as extruded cable duct covers (table 1).

Table 1. Materials used for present investigation

Material	Name	Specification
PC/ABS	Standard PC/ABS	No further additives, flame retardant
PC	PC mineral	Mineral reinforced, flame retardant
PC/ABS	PC/ABS custom 1	Unknown additives, flame retardant
PC/ABS	PC/ABS custom 2	Unknown additives, flame retardant
PC/ABS	PC/ABS custom 3	Unknown additives, flame retardant
PC/ABS	PC/ABS custom 4	Unknown additives, flame retardant

2.2. *Tensile testing*

According to DIN EN ISO 527 coupons type 1B were taken directly from all six PC based cable duct materials. Coupons were taken laterally to the extrusion direction from cable duct covers. Tensile testing was performed using Zwick/Roell ZMART PRO (Ulm, Germany) with 100 kN nominal power. Stress and strain were observed at room temperature and different testing speeds (50 mm/min, 100 mm/min and 400 mm/min). Five samples were tested per velocity and material with the strain being recorded by the traverse movement.

2.3. *High-speed tensile testing*

In accordance to DIN EN ISO 572 high-speed tensile testing with samples according to DIN EN ISO 527 type 1B was carried out at room temperature with a specifically designed test device (figure 3).

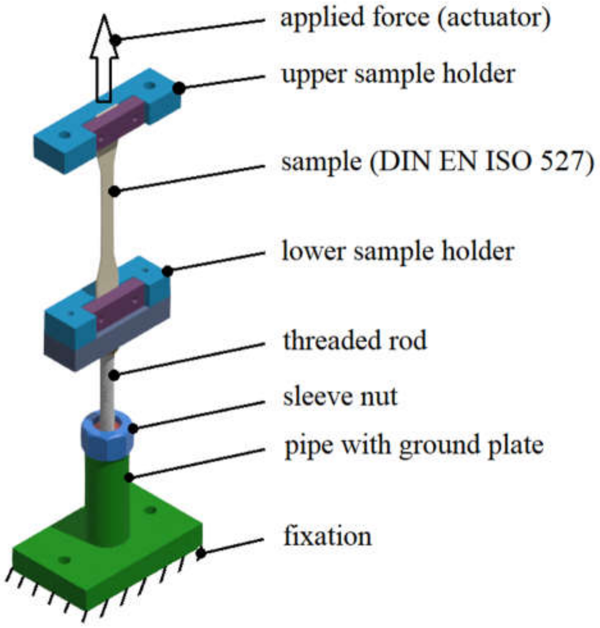

Figure 3. Specifically designed test device for high-speed tensile testing

The test setup enables the actuator to accelerate the sample with its holders and the threaded rod to the required test speed of 36.000 mm/min before the force is applied to the sample abruptly (figure 4).

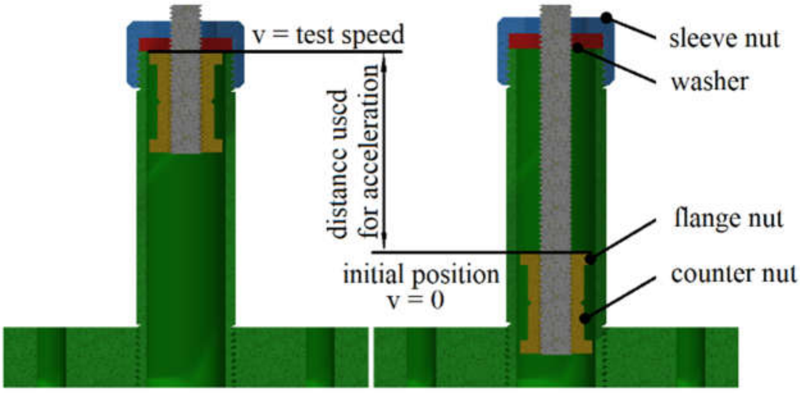

Figure 4. Mechanical structure of the acceleration device

A high-speed electro mechanic press is used as actuator (figure 5). Five samples were tested per material.

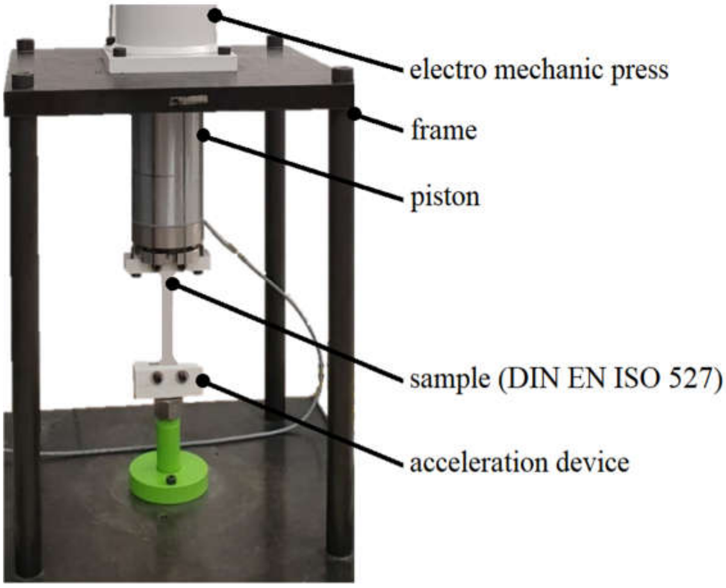

Figure 5. Experimental setup of the high speed tensile tests

After testing the length of both parts of the samples tested conventionally as well as via high-speed tensile tests was measured. Subsequently the remaining plastic strain ε_{plast} could be determined by calculating the elongation at rupture according to DIN EN ISO 527.

3. Results

3.1. Tensile testing

The tensile strength σ_m (figure 6) increases slightly with increasing test speed v for all materials. Standard deviations are generally low, but all PC/ABS materials exhibit higher mean values than mineral reinforced PC. The mean values seem to increase slightly with increasing test speed v.

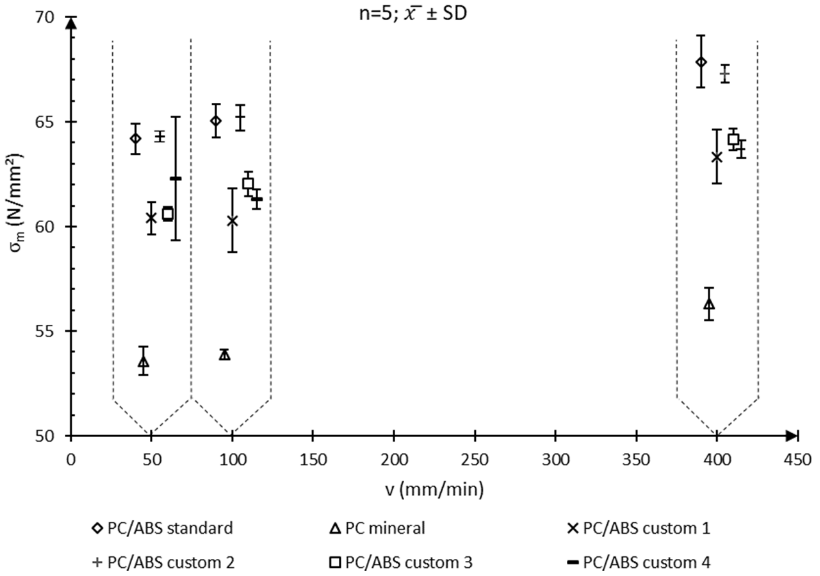

Figure 6. Tensile strength derived from tensile testing as a function of speed during testing

The strain at tensile strength ε_m (figure 7) of all materials exhibits little to no dependency on the test speed v showing a high reliability due to small standard deviations.

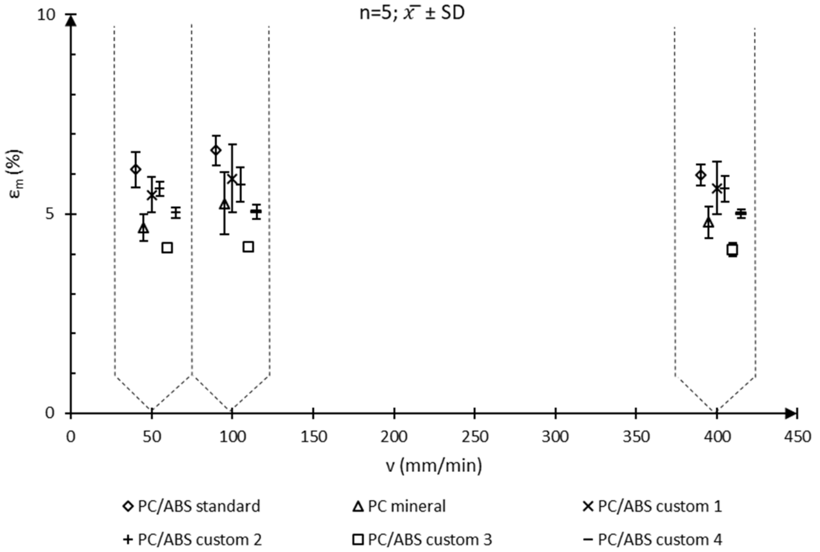

Figure 7. Strain at tensile strength derived from tensile testing as a function of speed during testing

The stress at break σ_b (figure 8) mean values seem to converge at approx. 53 N/mm^2 when the test speed v raises to 400 mm/min. PC mineral, PC/ABS standard and PC/ABS custom 3 show an increase in their mean values with increasing test speed v. The mean values of PC/ABS custom 2 and PC/ABS custom 4 exhibit opposite behavior and lower mean values as a function of increasing test speed v. The mean stress at break σb values of PC/ABS custom 1 decrease with increasing test speed v up to 100 mm/min and then increase again as the test speed increases further. The standard deviation of PC mineral and PC/ABS standard increases with increasing test speed v. In contrast, the standard deviation of PC/ABS custom 3 and PC/ABS custom 4 decreases with increasing test speed v. The standard deviation of PC/ABS custom 1 and PC/ABS custom 2 shows little to no dependence on the test speed.

Where PC/ABS custom 1 consistently shows relatively high standard deviations and PC/ABS custom 2 consistently shows relatively small standard deviations.

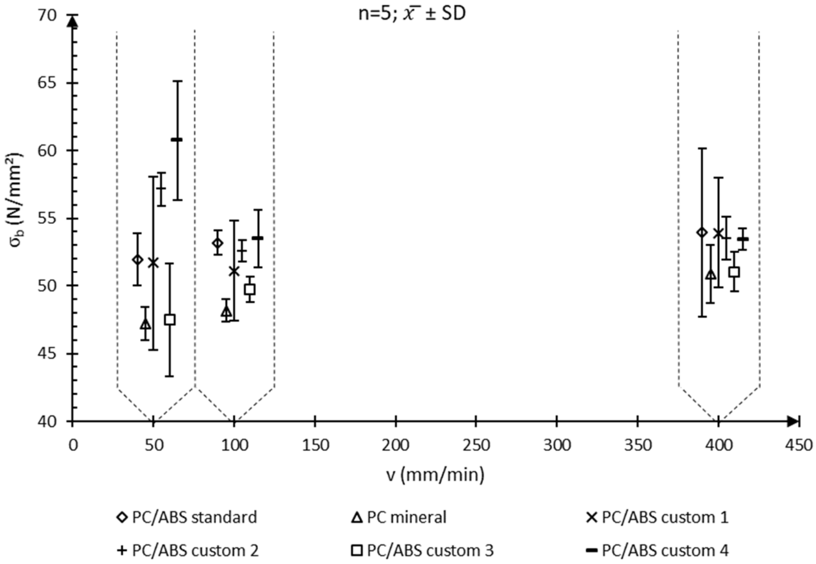

Figure 8. Stress at break derived from tensile testing as a function of speed during testing

All PC/ABS customized materials show decreasing mean values for strain at break ε_{tb} (Figure 9) with increasing test speed v. PC mineral shows relatively constant mean values with small standard deviations independent of the test speed v. PC/ABS standard initially shows an increasing mean value, which decreases again with further increasing test speed. The standard deviation of PC/ABS standard and PC/ABS custom 3 decreases with increasing test speed, while PC/ABS custom 2 and PC/ABS custom 4 show an increase of the standard deviation with increasing test speed. PC/ABS custom 1 shows a relatively constant large standard deviation with little to no dependence on the test speed.

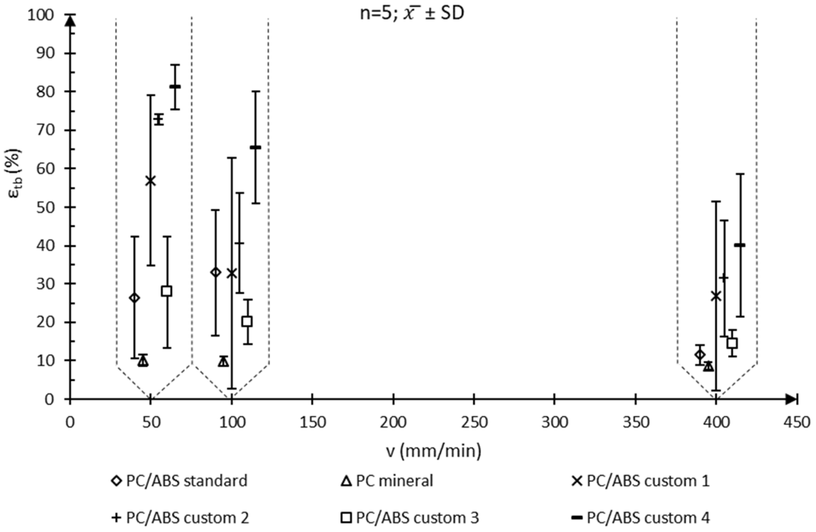

Figure 9. Strain at break derived from tensile testing as a function of speed during testing

In summary, it may be assumed that the mechanical material properties relevant for high speed punching: strain at break ε_{tb} and stress at break σ_b converge with increasing test speed v. The stress at break values range between approx. 43 N/mm² and 65 N/mm² at a test speed of 50 mm/min and between approx. 48 N/mm² and 60 N/mm² at a speed of 400 mm/min. With the exception of PC/ABS standard and PC/ABS custom 1, all materials show small standard deviations at a test speed of 400 mm/min. This finding is in good agreement to the strain at break values. At a test speed of 50 mm/min the values range between approx. 8 % and 97 %. At a test speed of 400 mm/min, the measured values are approx. between 3 % and 60 %.

3.2. High-speed tensile testing

When comparing the remaining plastic strain $\varepsilon_{plast.}$ (figure 10) at different test speeds, the mean values for all materials tested converge between approx. 5 and 20 % remaining plastic strain at a test speed of 36.000 mm/min. Furthermore, the comparatively small standard deviations show reliable mean values. At the speeds of 100 and 400 mm/min the standard deviations of the material PC/ABS custom 1 reaches into the negative range. Because this is physically not possible the graph figure 10 does not display these standard deviations. The most possible reason is a too small sample size which could also be the reason for the large standard deviation of other materials.

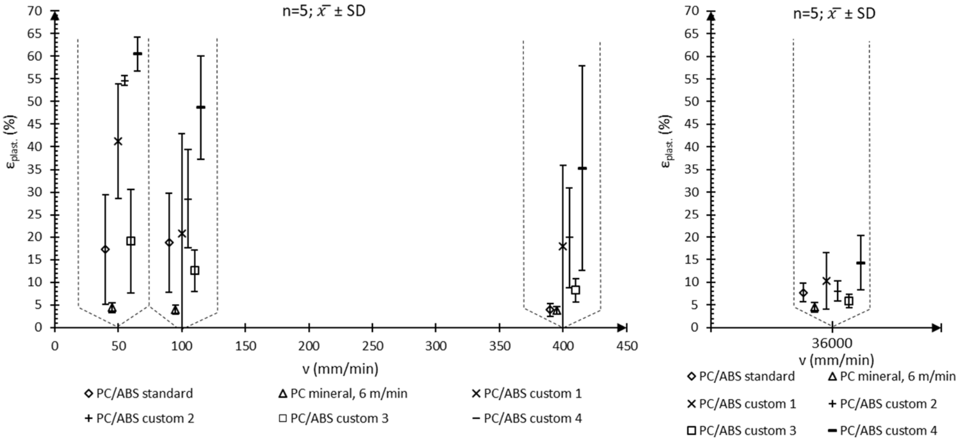

Figure 10. Remaining plastic strain of the destroyed samples at 50, 100, 400 (left) and 36.000 mm/min (right) test speeds

4. Discussion

All results support our assumption (and research question) that higher testing speeds respectively process speeds result in lower remaining plastic strain. Here the remaining plastic strain is correlated to the main burr cause. During the punching process, however, shear stresses and not tensile stresses affect the material. Therefore, the values obtained for remaining plastic strain are not fully transmissible. Nevertheless, remaining plastic strain is a good parameter for the plastic deformation behavior of a material and therefore for burr formation. It is also interesting that the remaining plastic strain mean values of the different materials converge as the test speed increases. This could indicate that only one tool configuration is sufficient for processing a large number of PC based materials as long as the process speed is chosen correctly. The conventional tensile tests were initially carried out at a strain rate of 1 mm/min, according to DIN EN ISO 527, after which the test machine accelerated to the actual test speed. However, during the tests at 36.000 mm/min, the load was applied abruptly, just as in the punching process. This increases the significance of the data derived from the high speed tests but lowers the comparability to data obtained via different test set-ups.

Parallel investigations of the punching process with a high-speed camera have also shown that film formation is strongly related to elongation at break [10]. The recordings show that the punched slug remains connected to the base material in the geometry of a film for a relatively long punch travel. This could indicate that burr as well as film formation can be reduced by applying higher process speeds.

5. Conclusion

The tensile behavior of common PC based materials used in cable duct production was investigated in order to reduce the burr formation during manufacturing. The elongation behavior of tests carried out at 50, 100 and 400 mm/min according to DIN EN ISO 527 were compared to tests using a custom test rig under a rapid loading with 36.000 mm/min test speed. Comparing the remaining plastic strain of the destroyed samples higher test speeds lead to lower remaining plastic strain. The remaining plastic strain is considered a measure for burr formation during the punching process, which decreases with increased test or process speed. Although mainly shear forces and no tensile forces occur in the punching process normalization of the measured remaining plastic strain mean values by comparison with burr heights is possible taking into account the described test or punching speeds. In addition, with increasing process speed the mechanical properties of different material qualities converge. This leads to the hypothesis that a single tool configuration can be used for different material grades if a high process speed is applied.

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