

Process Development: Burr and Film Formation during High Speed Punching of Extruded PC Based Polymers

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Abstract. First investigations focus on the usage, processing and material properties of polycarbonate (PC) based materials used in cable duct production. Test coupons were taken from in-situ cable ducts including further additives generally used in industry. Different mechanical and optical analytical methods were performed. Significant differences in tensile properties of polycarbonate/ acrylonitrile butadiene styrene (PC/ABS) compared to mineral reinforced PC were observed. The hardness of mineral reinforced PC is significantly dependent on the geometry of the cable ducts. The fracture behavior and morphology of the PC/ABS fracture surface is directly related to the coupon temperature during Charpy impact testing. The process temperature influences the failure behavior during high impact processing such as high speed punching. Due to the lower impact strength of mineral reinforced PC less film and burr formation compared to PC/ABS are likely. However, the mineral distribution is not homogeneous and therefore subject to further investigation. This study aims at a better understanding of process properties of PC/ABS products, parameter selection, quality improvement and general understanding of underlying microstructural and surface properties.

Introduction

The standard material for cable ducts is polyvinyl chloride (PVC). To prevent PVC releasing hydrochloric acid (HCl) during heating [1] thermal stabilizers are mixed into the polymer granules. The stabilizers work sufficiently for short-term temperature rises up to approx. 210 °C, but fail at longer exposure or higher temperature. Therefore, industry started using the halogen-free thermoplastic polymer blend polycarbonate acrylonitrile-butadiene-styrene (PC/ABS) for cable ducts. PC/ABS is self-extinguishing and can reach the highest level V-0 in the UL94 test for flammability of plastic materials [2, 3]. This is achieved, for example, by the toxicologically harmless addition of phosphates [4]. Unfortunately, PC/ABS tends to burr and forms films during punching which makes the final product unserviceable (Fig. 1).

PC/ABS is a ternary polymer blend consisting of the thermoplastic polymer polycarbonate (PC), the thermoplastic copolymer styrene acrylonitrile (SAN) and the SAN grafted polybutadiene rubber (BR) [4]. PC/ABS is used for various automotive, electronics and telecommunication applications and is therefore available in multiple configurations regarding structure and material properties. Various studies focus on optimization and analysis of material properties which strongly depend on the ratio between PC and ABS, the rubber content of ABS, further additives or process parameters while blending and extruding [5-9]. In addition, the material behavior depends largely on whether the continuous phase is PC or ABS or whether an immiscible 50/50 mixture is present [10].

This research focuses on the reduction of burr and film formation during punching of PC/ABS and further PC based materials used in cable duct manufacturing. However, it is quite a problem to obtain knowledge on material qualities due to the cable duct industry keeping material specifications (like the ratios of the polymers blended or additives included) as company secrets. To get a deeper understanding of microstructural behavior and failure mechanisms different material qualities used in cable duct production were analyzed. This work therefore also aims at identifying the dominating

failure cause to understand in-situ material behavior regarding burr and film formation and to be able to adapt the manufacturing process to various other PC based materials like different PC/ABS qualities.

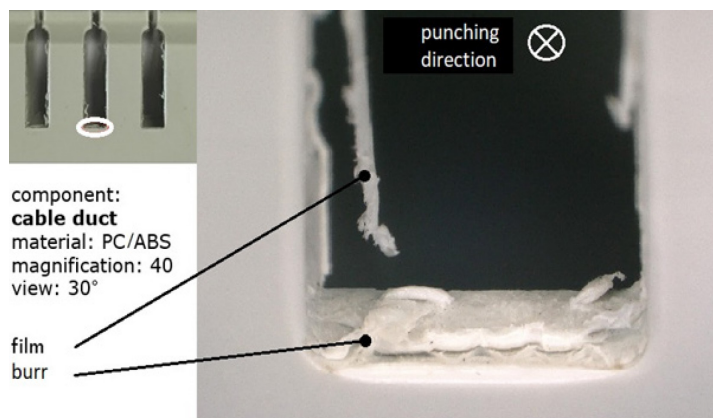


Figure 1. In-situ burr and film formation on PC/ABS cable duct during punching.

Materials and Methods

Materials. Polycarbonate acrylonitrile-butadiene-styrene (PC/ABS) polymer blend and mineral reinforced polycarbonate (PC) were delivered as extruded cable ducts with corresponding covers and extruded PC/ABS plates with 4 mm thickness. Two different qualities of flame retardant PC and one flame retardant PC/ABS quality were examined: standard PC/ABS, mineral reinforced PC with an extrusion speed of 3 m/min and identical mineral reinforced PC with an extrusion speed of 6 m/min. Besides the mentioned materials, extruded plates with 4 mm thickness of standard PC were investigated.

Charpy Impact Testing. According to DIN EN ISO 179-1/1eA notched coupons type 1A (thickness 4 mm) were taken from extruded plates of standard PC/ABS and PC lateral to the extrusion direction. Tests were performed using an Amsler Pendelschlagwerk analog PSW300 (Neftenbach, Switzerland) with a pendulum's nominal energy of 300 J. Before testing the coupons were tempered at room temperature, 40 °C and 80 °C in flowing air in a laboratory furnace Nabertherm Modell N 15/65HA (Lilienthal, Germany). The temperature control was performed using an Infratec FLIR I7 thermal camera (Dresden, Germany). The impact strength of 10 coupons was obtained for each temperature and material.

Vickers Hardness Testing. Hardness testing of cable duct covers was performed according to Vickers following DIN EN ISO 6507-1 via Wolpert Dia Testor 7021 (Aachen, Germany) with HV1 settings. Dependent on the respective geometry indentation was carried out at different positions (Fig. 2): Five test indentations at room temperature followed a strict straight line for each sample geometry and sample area.

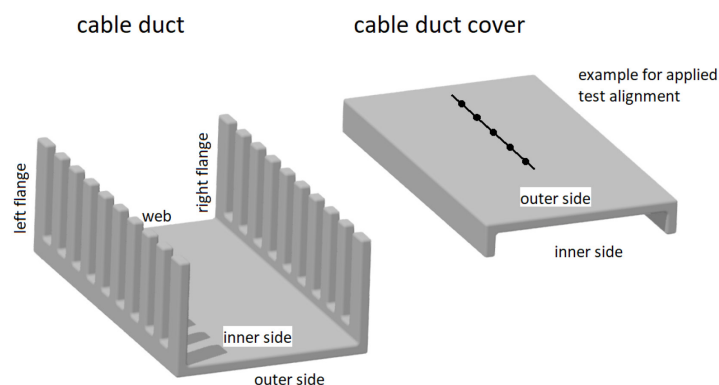


Figure 2. Designations of the cable duct and corresponding cover.

Tensile Testing. Tensile testing was realized according to DIN EN ISO 527-1, -2. Coupons type 1B (thickness 1.11 mm to 1.24 mm) taken directly from mineral reinforced PC types and PC/ABS type cable ducts were orientated laterally to the extrusion direction. Tests were performed at room temperature using Zwick/Roell Zmart.Pro (Ulm, Germany) with 100 kN nominal force. Stress and strain were observed at testing speeds of 50 mm/min, 100 mm/min and 400 mm/min with the strain being recorded by the traverse movement of the testing machine. 5 coupons were tested for each velocity and material.

Optical Analysis. The fracture surfaces of coupons used for Charpy impact testing were analyzed using a Keyence VHX 5000 optical microscope (Osaka, Japan).

Results

Because industry does not provide sufficient information regarding engineering materials used in cable duct production the general purpose of this study was to generate basic knowledge on material properties, microstructure and failure behavior. Mechanical values and fractural behavior were observed at either different temperatures, positions or testing speeds to adjust the manufacturing process in terms of reduced burr and film formation.

As demonstrated in Fig. 3 the notched Charpy impact strength a_{cN} of PC/ABS rises with increasing coupon temperature T_C . A relatively big scatter range of the impact strength is observed possibly due to immiscibilities within the microstructure, which will be subject to further investigations. Comparing these results to results obtained for pure PC, pure PC has higher impact strength independent of the temperature (Fig. 4). At room temperature the scatter range for PC is rather large. Four out of ten coupons showed a similar impact strength of about 122 kJ/m² which was also measured at 40 °C and 80 °C. Six coupons failed at a relatively low impact strength and will be subject of future fractural analysis. However, first conclusions state that PC has two failure modes at room temperature, brittle as well as ductile.

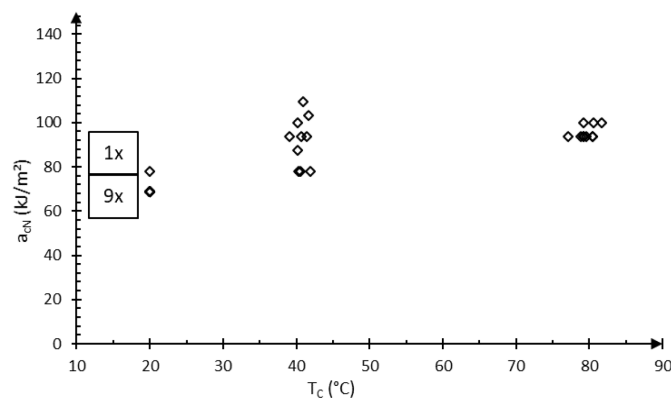


Figure 3. Notched Charpy impact strength for PC/ABS as a function of temperature.

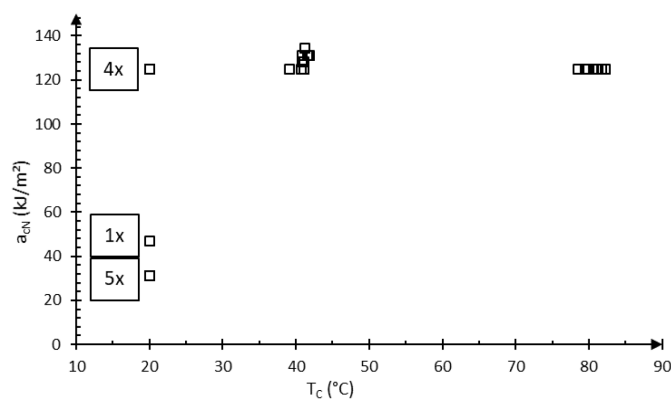


Figure 4. Notched Charpy impact strength pure PC as a function of temperature.

The hardness of PC/ABS (Fig. 5), approximately 29 HV1 with only small deviation from the mean value, is therefore reliable regarding both, inner and outer side of the cable duct. Still, hardness values differ significantly regarding the position: in comparison to PC/ABS the mineral reinforced PC manufactured at 3 m/min and also at 6 m/min extrusion speed shows a small scatter range of the hardness values on the inner side but a large scatter range for values obtained on the outer side. This may likely be due to minerals not being distributed evenly within the entire cross section of the cable duct. Not only the position, but also the extrusion speed significantly influences the hardness of the material: smaller values are detected for the mineral reinforced PC with an extrusion speed of 6 m/min compared to the quality extruded with 3 m/min.

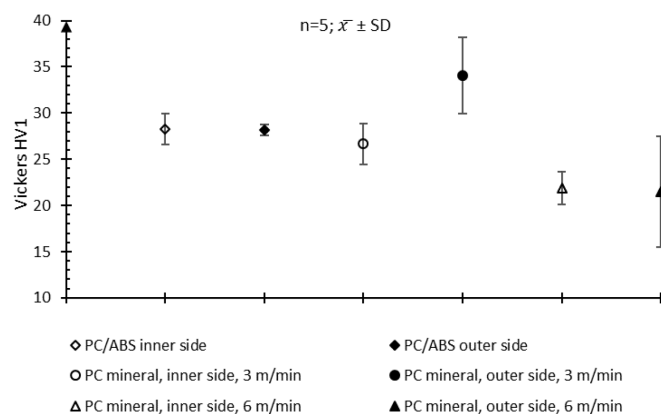


Figure 5. Vickers hardness on inner and outer side of PC/ABS and mineral reinforced PC cable ducts.

The tensile strength σ_m (Fig. 6) rises with an increase of test speed v for all materials tested revealing relatively low standard deviations. All materials have a relatively similar dependence on the test speed and thus a similar characteristic curve. Lower tensile strength values are observed for mineral reinforced PC materials compared to PC/ABS and for the PC quality with higher extrusion speed.

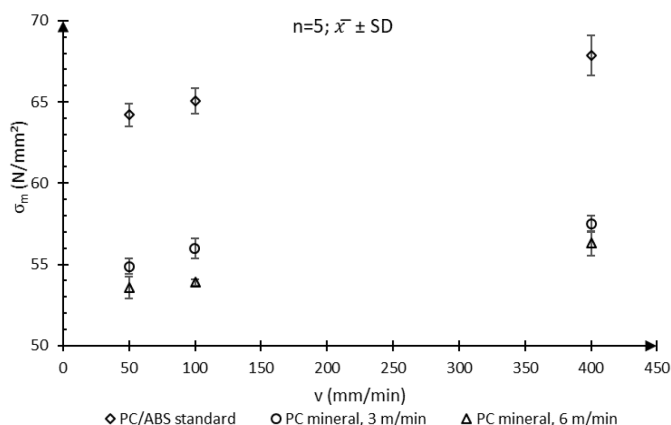


Figure 6. Tensile strength derived from tensile testing as a function of speed during testing.

The strain at tensile strength ϵ_m (Fig. 7) also shows a similar characteristic curve for all materials investigated showing a high reliability due to small standard deviations. Strain at tensile strength slightly rises from 50 mm/min to 100 mm/min test speed and then slightly decreases again when the test speed is raised to 400 mm/min. Because of only small changes in strain at tensile strength with increased test speed, no significant dependence on test speed can be reported. Only, slightly smaller values are detected for mineral reinforced materials and for the PC quality produced at higher extrusion speed.

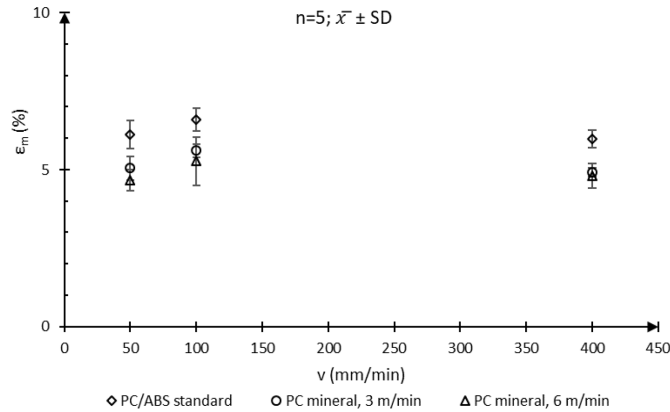


Figure 7. Strain at tensile strength derived from tensile testing as a function of speed during testing.

The stress at break σ_b of all investigated materials (Fig. 8) increases slightly with increasing test speed. Small standard deviations are observed for all materials and test speeds except for PC/ABS at a test speed of 400 mm/min.

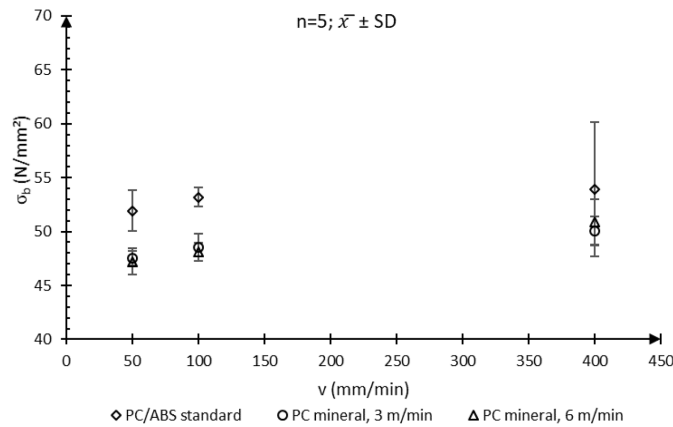


Figure 8. Stress at break derived from tensile testing as a function of speed during testing.

The strain at break ϵ_{tb} (Fig. 9) shows constant values for mineral reinforced PC materials. Here approximately 10 % with small standard deviations is measured independent from test speed. PC/ABS shows big standard deviations subjected to lower test speeds but a small deviation for a test speed of 400 mm/min. PC/ABS coupons fail at low test speeds under relatively constant stress at break values with varying strain at break values. At 400 mm/min test speed this effect reverses. PC/ABS coupons fail at relatively constant strain at break under varying stress at break values. Moreover, the observed strain at break is similar for all materials tested at 400 mm/min test speed.

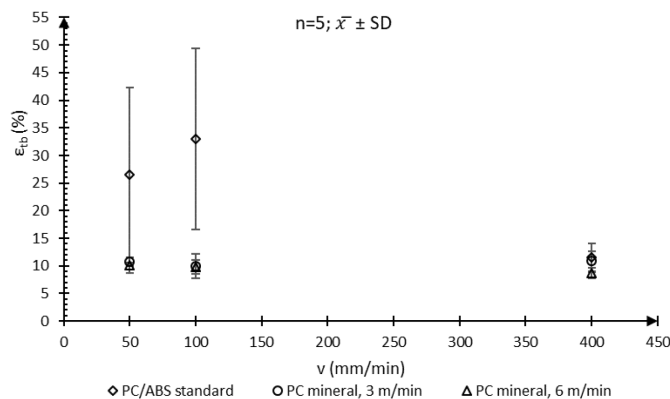


Figure 9. Strain at break derived from tensile testing as a function of speed during testing.

As shown in Fig. 10 the macroscopic fracture surface of notched Charpy impact PC/ABS coupons become smoother with increasing coupon temperature. At the same time the ductility increases. Increasing plastic deformation is shown clearly by necking and the decreasing cross section of the residual sample. This correlates well to the slightly increased impact strength demonstrated earlier.

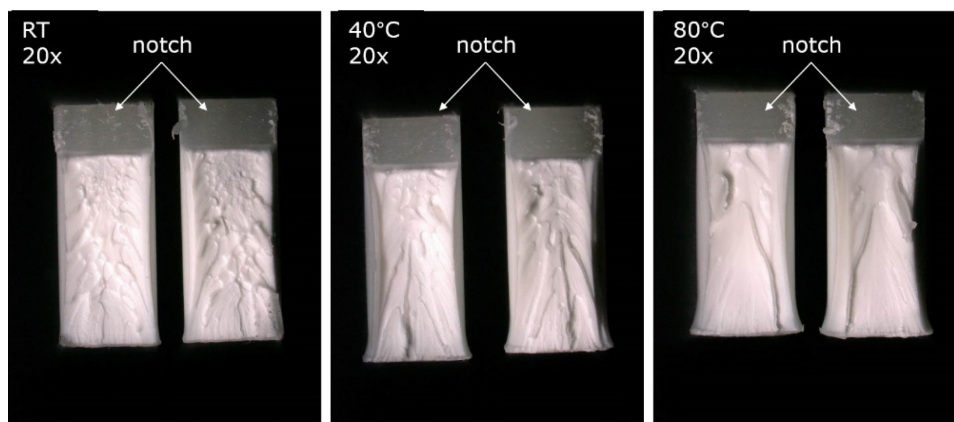


Figure 10. Failed PC/ABS Charpy Impact coupons at different temperatures.

Figure 11 shows three similar surface morphologies of failed PC coupons related to similar impact strength values (Fig. 4) of about 122 kJ/m². As expected, similar values are in agreement to similar fracture appearances independent from coupon temperature.

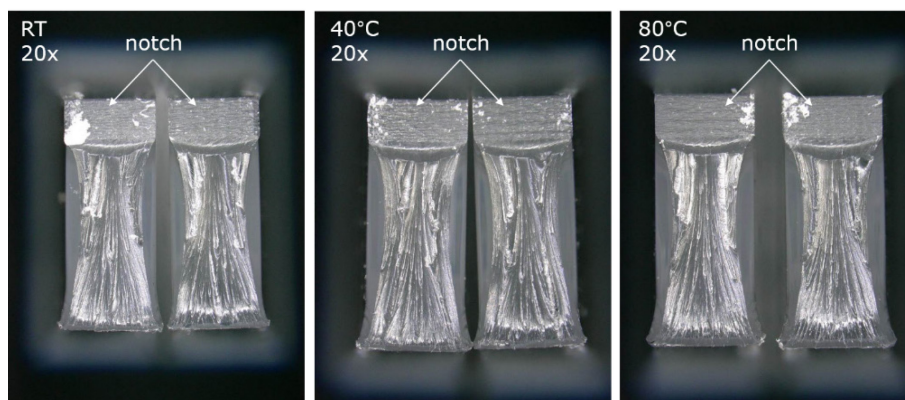


Figure 11. Failed pure PC Charpy Impact coupons at different temperatures.

However, strongly different impact strengths were observed at room temperature. Fig. 12 shows PC coupons that failed either in ductile (a) or brittle (b) mode at room temperature. Probably the ductile-brittle transition temperature of the examined PC quality is located around room temperature depending on coupon thickness and impact speed. However, fracture analyses of both, ductile and brittle failure modes of PC at room temperature will be subject to further investigation.

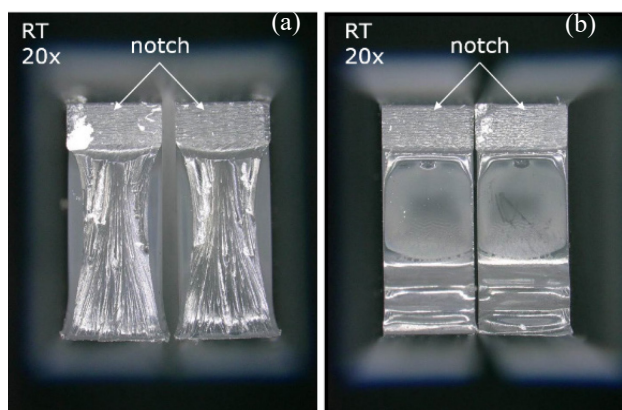


Figure 12. Failed pure PC Charpy Impact coupons at different failure modes.

Discussion

In agreement to results obtained via notched *Charpy impact tests* the optical analysis demonstrates that the PC quality can fail in both, ductile as well as brittle mode around room temperature. The appearance of the fracture surface of coupons failing in ductile mode correspond to those obtained for coupons tested at higher temperatures which exclusively failed in ductile mode. Therefore, the temperature is of little to no influence on the fracture appearance of PC coupons failing in the ductile mode.

The fracture appearance as well as the impact strength of the PC/ABS coupons depend on the test temperature. Since less plastic deformation can be detected at lower temperatures it is concluded that low temperatures are advantageous regarding burr and film formation.

Vickers hardness testing of cable duct covers showed constant values for PC/ABS with low standard deviations. Varying hardness with big standard deviations was observed for mineral reinforced PC depending on the position of the Vickers indentation. This leads to the hypothesis that the minerals are not homogeneously distributed over the entire cross-section. It may be that the minerals act as break points and thus have positive effects regarding less plastically deformation during the rupture occurring in the punching process. Therefore, it is strongly recommended to use material in which the minerals should be homogeneously distributed.

Tensile testing revealed that for PC/ABS higher test speeds lead to relatively low strain at break values with small standard deviation. Low test speeds lead to large standard deviations and therefore less reliable values. For the punching process predictable strain at break values are beneficial for the optimization of the process. In addition, low strain values (achieved at high tests speeds) during punching are advantageous regarding burr and film formation because the material can be fully cleared during punching depending on its elongation behavior. The large standard deviation of the stress at break occurring here is irrelevant since it fluctuates around a relatively small mean value which can be overcome by the punching machine. Furthermore, PC/ABS and mineral reinforced PC were observed to exhibit very similar behavior regarding strain at break at 400 mm/min test speed. This gives rise to the hypothesis that PC based materials behave similarly under rapid loading and thus influences of mineral reinforcement or ABS disappear. If this is the case, a tool with suitable process parameters could be used for almost all PC based materials. This is to be proven by the investigation of further PC based cable duct materials. In addition, the extent to which the results obtained at a test speed of 400 mm/min can be transferred to the punching speed of 600 mm/s still has to be investigated.

Conclusion

Test coupons from polycarbonate PC and polycarbonate/ acrylonitrile butadiene styrene (PC/ABS) were taken from in-situ cable ducts generally used in industry. The hardness of mineral reinforced PC is significantly dependent on the geometry of the cable ducts. In a first approach this is related to the inhomogeneous distribution of mineral additives within the polymer matrix leaving the conclusion to only use PC materials with homogeneously distributed additives. However, under rapid loading the influence of mineral reinforcement or ABS in PC is significantly lowered. Because for PC/ABS higher test speeds lead to reliable and relatively low strain at break values the punching process should be operated rather at higher speeds being advantageous regarding burr and film formation because the material can be fully cleared during punching.

The fracture behavior and morphology of the PC/ABS fracture surface is directly related to the coupon temperature. PC quality can fail in both, ductile as well as brittle mode around room temperature. While the temperature does not significantly influence the fracture appearance of PC coupons failing in the ductile mode, PC/ABS coupons show a temperature dependency. Low temperature associated with little plastic deformation is advantageous regarding burr and film formation. Less film and burr formation is likely for mineral reinforced PC compared to PC/ABS.

These results are a first approach to better understand the polymer behavior during punching and topics as mineral distribution, speed of punching, additives, and temperature during the process are subject to further investigation.

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