

## Role of PET in improving wear properties of PP in dry sliding condition

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**Abstract.** The sliding wear of isotactic polypropylene (PP), polyethylene terephthalate (PET) and their blends was evaluated as a function of applied pressure and composition against a stainless steel counter face in dry condition. Wear rate decreases with the addition of PET in the blend. The wear was observed in two stages, the moderate wear and high wear while increasing the applied pressure on test samples. The addition of PET in PP helps in increasing the limit of moderate wear towards the high-pressure side. Microstructure and worn surfaces of samples were observed by scanning electron microscope. The wear phenomenon has been discussed based on wear losses and worn surfaces.

**Keywords.** Sliding wear; PP; PET; blend.

### 1. Introduction

Polymers are used as dry sliding materials in many precision instruments and machines. They are especially suitable for environments, where use of external lubricants is totally prohibited (Santner and Czichos 1989; McNicol *et al* 1995; Lu and Friedrich 1995). The materials with unique combination of good friction and wear properties along with easy processability are in need. This can be realized by blending polymers. It is necessary to understand the tribological properties of these blends. The friction and wear behaviour of polymer blend is fairly complex because the individual components have their unique response towards the friction and wear. Further, the extension and distribution of individual polymer and its interphase, are also important in determining the performance of the whole system (Santner and Czichos 1989).

Polyethylene terephthalate (PET) is a semi crystalline polymer widely used for packaging, electronic parts, and is especially suitable for making gears and bearings, because of high wear resistance, general toughness, fatigue resistance and availability of high purity recycled resin (McCrum *et al* 1988). The sensitivity to brittle fracture due to notch and stress concentration restricts its applicability. The considerable distortion, shrinkage and clouding of PET make its moulding difficult. On the other hand polypropylene (PP) can be processed very easily however, the sliding wear properties are inferior (Chand and Fahim 2000). The sliding wear of PP can be

improved significantly by the addition of ultra high molecular weight polyethylene (Hashmi *et al* 2001). Efforts have been intensified to develop PP/PET blends due to their potential for various engineering applications (Danaklon 1989; Hayes 1989; Xanthos *et al* 1990). Addition of PET in PP resulted in modulus increase that was independent of type of PP and presence of additives (Xanthos *et al* 1990). Improvement in mechanical properties was observed when acrylic acid functionalized PP was blended with PET. The PET has been blended with other polyolefins such as the high density polyethylene (HDPE) and the oriented blends of PET/HDPE were investigated. Simultaneously stretched blends show better physical properties than the sequentially oriented blends. The blends with compatibilizers show strain hardening effect whereas without compatibilizer does not show strain hardening upon orientation (Samaru and Jabarin 1993). PP/PET blends have been studied for observing the effect of blend composition on permeability (Bataille *et al* 1987).

In the present study, by using the melt blending technique, we have developed the blends of PP and PET of various compositions. The morphology and worn surfaces of PP/PET blends were studied using scanning electron microscopy. Sliding wear properties of these blends have been determined and studied for various blend compositions.

### 2. Materials and methods

#### 2.1 Materials

Isotactic polypropylene PP (density 0.91 g/cc, grade SRM 100 N) was obtained from M/s Indian Petrochemicals

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Ltd., Vadodara and polyethylene terephthalate PET (density 1.39 g/cc) was obtained from M/s Century Enka Ltd., Pune, India.

## 2.2 Preparation of blend

PP and PET granules were kept in air circulating oven at 100°C for 24 h to dry the materials. The dried materials were mixed in a single screw extruder having L/D ratio 27.5. The temperatures of feed, compression and metering zones were kept at 200, 270 and 280°C, respectively. Rotational speed of screw was kept at 20 rpm. Molten blend strand was quenched in water at 20°C and cut in the form of granules (length, 3–5 mm and diameter, 3 mm) by using a pelletizer. Compositions of samples are shown in table 1.

## 2.3 Preparation of test samples

The cylindrical pins were prepared by using a simple die and plunger system having an electrical heating arrangement. The details of this arrangement are given elsewhere (Hashmi *et al* 2001). Weighed amount of blend was fed into the die. Die was heated up to 180°C and the punch was pressed into the die. Die was cooled in water at 20°C. After the solidification of polymer blend, sample was taken out from the die.

## 2.4 Sliding wear test

Dry sliding wear tests were conducted on a pin-on-disc friction and wear-testing machine (Ducom Model No. 20 LE). The cylindrical pin specimens of size 8 mm diameter and 30 mm length were tested against EN-24 steel containing 0.59% carbon, 0.25% silicon, 0.8% manganese, 1.02% chromium, 0.30% molybdenum, 1.50% nickel disc of hardness 305 Hv. The tests were conducted at different pressures ranging from 0.3–0.9 MPa and sliding speeds ranging from 0.66–4.00 m/s. Wear rates were computed from the weight loss measurements. Specimen pin used in this study is flat ended and the radius of wear path is 6.36 cm. Sliding wear data reported here is the average

of at least 3 runs. Before taking the weight loss measurements, the surfaces of pins and steel disc were prepared to ensure maximum contact. The specimen pins were run on disc for various time intervals at low sliding speed until a profile was obtained on pin surface matching with the sliding surface of steel disc. It was ensured by observing the contact surface, which was distinguished from the rest of the cross-section of the specimen pin by using a magnifying glass. Using polishing paper after each observation, the steel disc was polished. The process was repeated until the visually observed contact area was more than 50% of the cross-section of the pin.

## 2.5 Microscopy

Scanning electron microscopy (JSM 5600, JEOL, Japan) was employed to observe microstructures of the blends and worn surfaces.

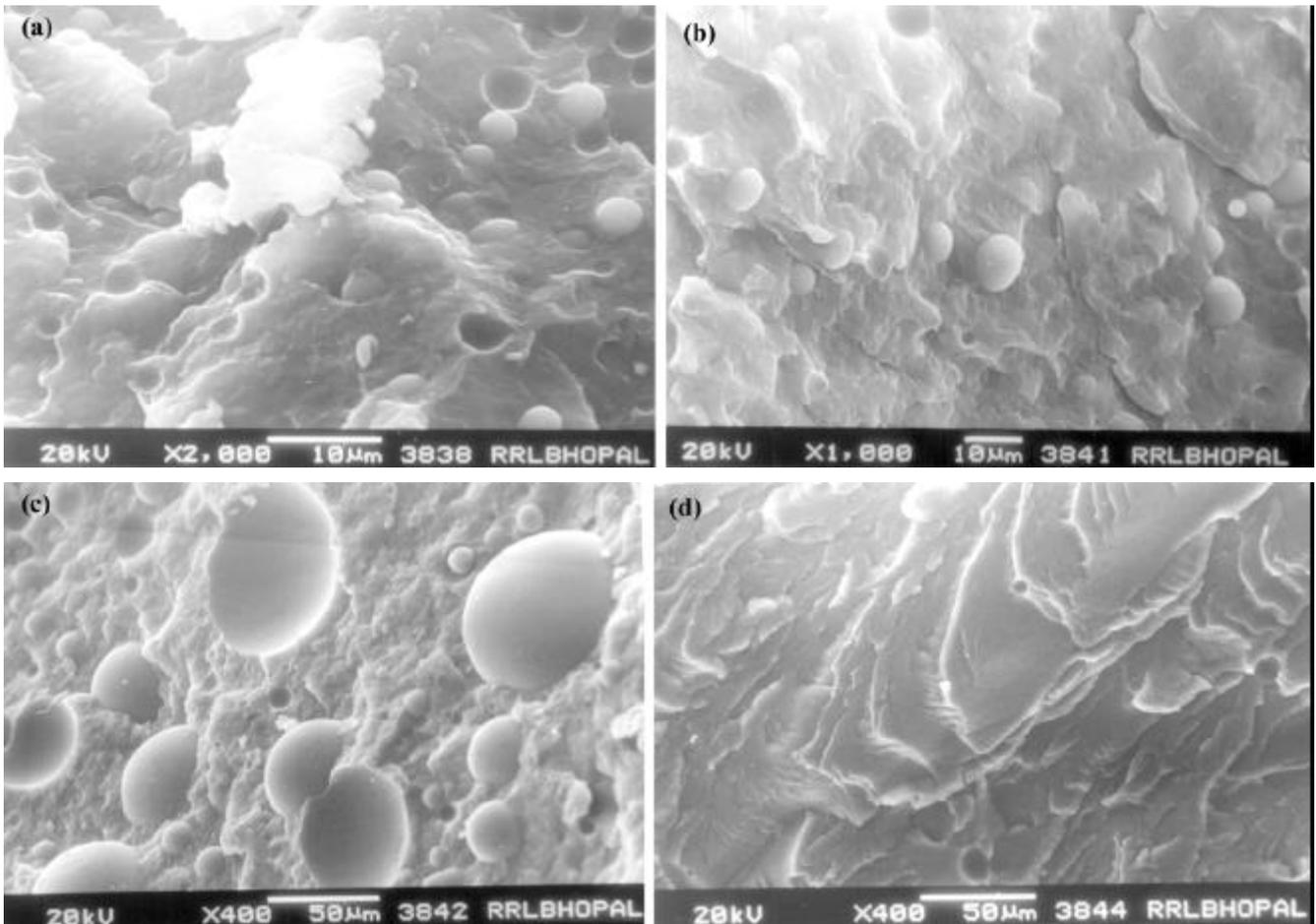
## 3. Results and discussion

Figure 1(a, b, c, d) illustrates the cryogenic fractured surfaces of PP/PET blends of 10, 15 and 30 wt.% of PET in PP and pure PET, respectively. Two-phase morphology is observed in all cases in which PET spherical balls are distributed in PP matrix. The cavities are also observed in the fractured surface indicating removal of PET balls. Smooth surface of balls shows that PP and PET form distinct phases and do not adhere with each other. The diameters of these spherical balls are different in different samples and increase with the increased weight per cent of PET in PP. In PP/PET-90/10 blend sample, the diameters of PET spherical balls were below 5 µm. The sizes of few balls were observed up to 8 µm in PP/PET-85/15 blend and 50 µm in PP/PET-70/30 blend. The uniformity in distribution of PET balls was better in PP/PET-90/10 and 85/15 as compared to 70/30. The balls of different sizes ranging from 3 µm to 50 µm were observed in PP/PET-70/30. The increase in size of few PET domains in PP/PET-70/30 blend is attributed to coalition of small PET domains on reduction of inter domain distances. The inter-domain distance shall reduce with increased concentration of PET in PP, assuming the size of domain remains constant. Similar results have been reported earlier where the size of domains of polycarbonate (PC) increased with the content of PC in PP (Chand and Hashmi 1998, 1999). Both PP and PET are incompatible and immiscible polymers and therefore, distinct phases are observed. The melting point of PET is 265°C and that of PP is 165°C. During solidification, PET solidifies first, whereas PP remains in the molten state due to the large difference in the melting points of two polymers. Therefore, PET is found in discrete form and PP forms the matrix.

Figure 2 is a plot of wear-rate vs applied pressure for PP, PET and their blends of different compositions at

**Table 1.** Composition of PP/PET blends.

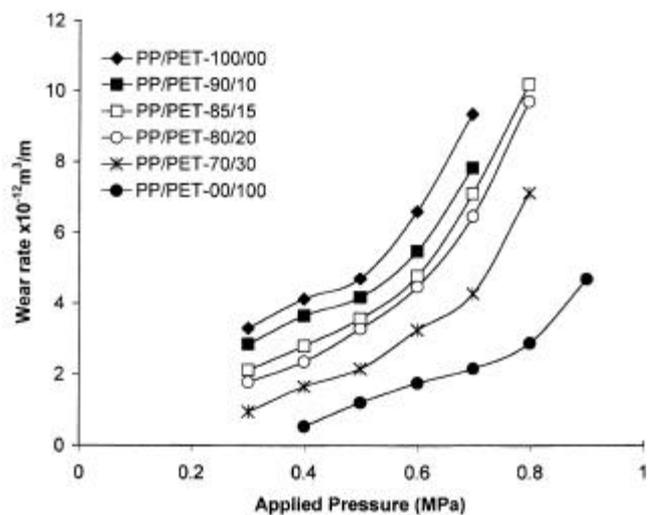
Sl. no.	Composition of PP/PET blends (wt. %)	
	PP	PET
1.	100	00
2.	90	10
3.	85	15
4.	80	20
5.	70	30
6.	00	100



**Figure 1.** SEM micrographs showing the distribution of PET in PP matrix. **a.** PP/PET, 90/10, **b.** PP/PET, 85/15, **c.** PP/PET, 70/30 and **d.** PET.

1.33 m/s sliding speed. In general, an increased applied pressure is associated with the increased wear rate of samples. PP shows maximum wear loss as compared to PET and PP/PET blends. PET shows minimum wear loss. Figure 2 also reveals that wear rate is observed in two stages, viz. moderate wear and high wear. The moderate wear is observed at low applied pressure, whereas at higher applied pressure, wear rate increases sharply. In other words, slope of the curve increases significantly indicating the high wear stage. The high-wear stage shifts to higher applied pressure with the increased PET content in the blend. PP shows moderate-wear up to 0.5 MPa of applied pressure beyond which the wear rate increases sharply with applied pressure. PET on the other hand shows moderate wear up to 0.8 MPa of applied pressure. The moderate wear of PP/PET lies in between 0.5 and 0.8 MPa pressure at constant sliding speed of 1.33 m/s. The extended moderate wear of PP depends upon the content of PET present in the blend.

Figure 3 shows the plot between wear rate and PP/PET blend composition at different applied pressures at constant sliding speed of 1.33 m/s. The addition of PET in PP improves wear resistance of PP. The PET is known for

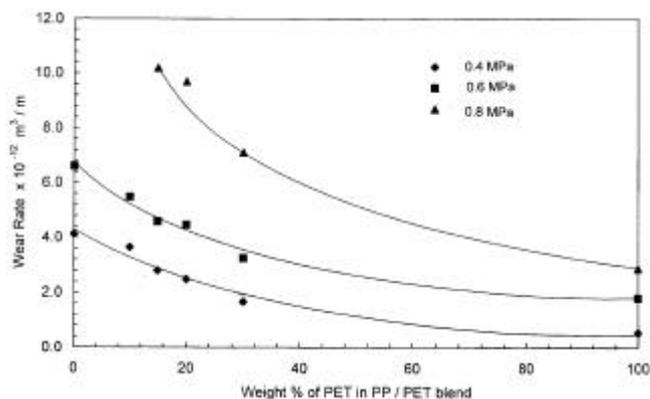


**Figure 2.** Plots between the wear rate and applied pressure for PP, PET and PP/PET blend system at 1.33 m/s sliding speed.

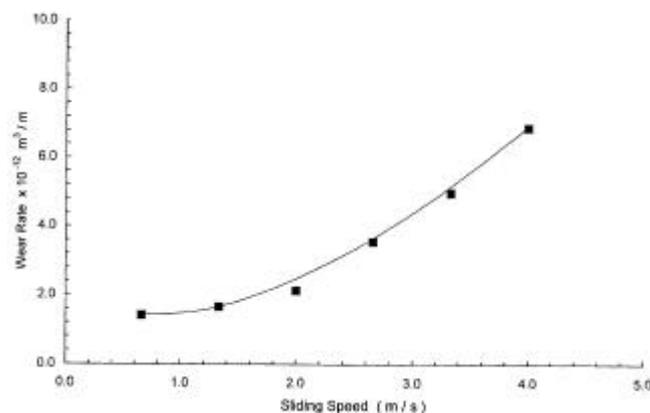
good wear resistance as compared to PP (McCrum *et al* 1988). At a fixed sliding-speed, an increase in applied pressure on specimen increases the wear rate of PP, PET and PP/PET blends. The situation was, however, impro-

ved by addition of PET in PP. At 0.4 and 0.6 MPa pressure the replacement of PET by PP in PP/PET blend increases wear rate. Both these curves are nearly parallel indicating the difference in magnitude of wear rate with increase in load remain unchanged, however at 0.8 MPa pressure the said difference increases with PP. This is attributed to wear performance of PP, which is highly sensitive to pressure as compared to PET. At 0.8 MPa pressure, it was not possible to test PP because the specimen deformed, losing its structural integrity. Similar observations have been reported when UHMWPE was added to PP (Hashmi *et al* 2001).

Figure 4 shows a plot between the wear rate and sliding speed for PP/PET-70/30 at 0.4 MPa applied pressure. The wear rate increases with the sliding speed. The increase in sliding speed is related to an increase in rate of strain, which leads to higher Young's modulus. On the contrary, a high sliding speed leads to higher temperature. The Young's modulus and strength of polymer decrease with increase in temperature. The effect of sliding speed on wear rate is the sum of both these effects (Song and Ehrenstein 1993).

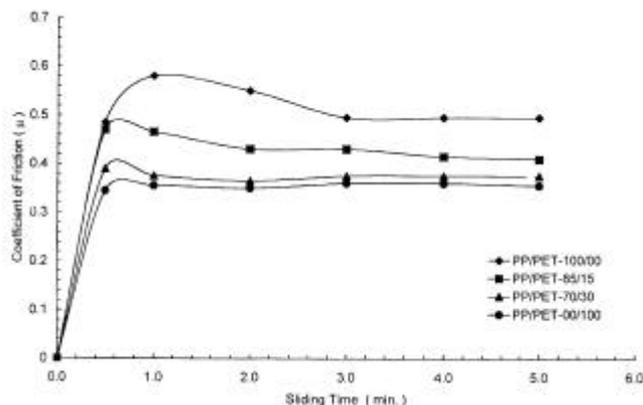


**Figure 3.** Plots between the wear rate and weight % of PET in PP/PET blend, at 1.33 m/s sliding speed.

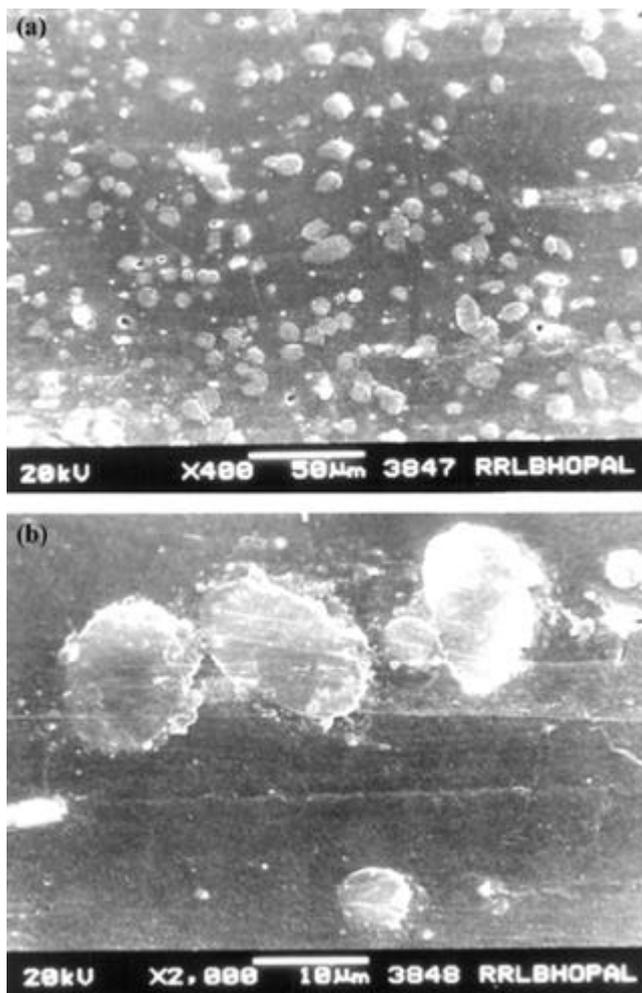


**Figure 4.** Plots between wear rate and sliding speed for PP/PET, 70/30 blends, at constant applied pressure of 0.4 MPa.

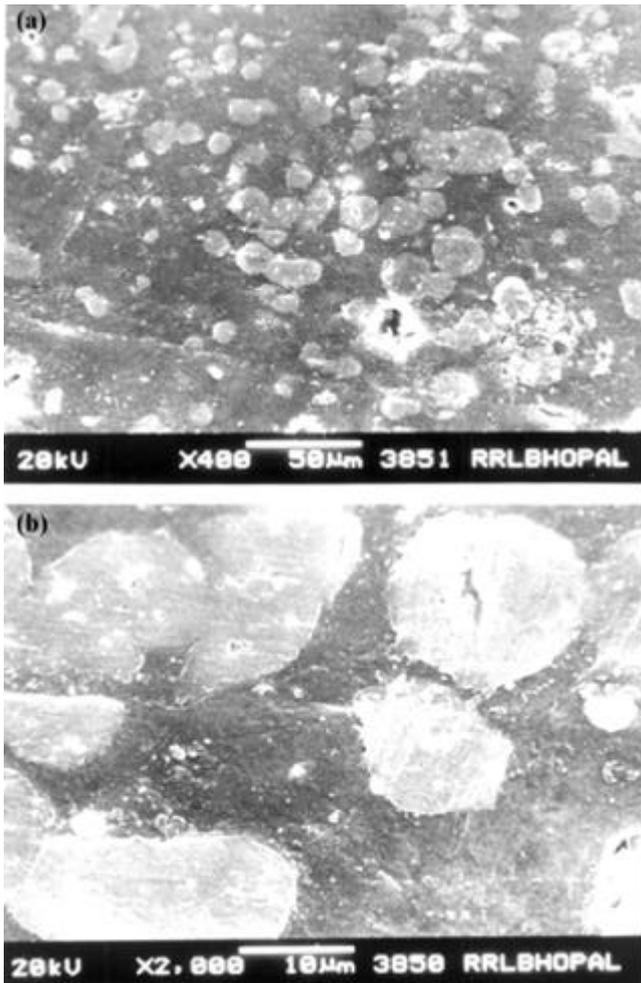
Figure 5 shows the variation of coefficient of friction with time for PP, PET and PP/PET blends at 0.4 MPa pressure and 1.33 m/s sliding speed. The PP shows higher



**Figure 5.** Plots between the coefficient of friction ( $\mu$ ) and time for PP, PET and PP/PET blend system at constant applied pressure of 0.4 MPa and 1.33 m/s sliding speed.



**Figure 6.** SEM micrographs of **a.** worn surface of PP/PET, 85/15 blend tested at 0.6 MPa pressure and 1.33 m/s sliding speed and **b.** magnified view of worn surface.



**Figure 7.** SEM micrographs of **a.** worn surface of PP/PET, 70/30 blend tested at 0.7 MPa pressure and 1.33 m/s sliding speed and **b.** magnified view of worn surface.

coefficient of friction as compared to PET. The blends of PP/PET show the values of coefficient of friction in between the values of PP and PET. The friction coefficient of PP increases rapidly to reach a maximum value and then reduces to a lower value. The change in coefficient of friction may be attributed to transfer of polymer film on rotating disc.

Figure 6 shows the micrograph of worn surface of PP/PET-85/15 blend tested at an applied pressure of 0.6 MPa and 1.33 m/s sliding speed. Figure 6a shows the distribution of PET balls in PP matrix. The smooth removal of PP matrix is also evident. It has been found that due to weak interaction between the PP matrix and PET balls, the small sized balls were removed leaving behind small pits. On further sliding, the matrix material PP was plastically deformed to cover the pits partially. A few pits are encircled and shown in figure 6a in which the sides of pits are covered by elongated PP. The groove was formed by the movement of dislodged PET balls, which was

trapped in the pit formed earlier. The magnified view (figure 6b) shows the formation of scratches on the surface of specimen as well as on PET balls in the sliding direction. The significant plastic deformation was not observed on PET balls and grooves were found without wedge formation. The absence of plastic deformation clearly shows the better wear performance of PET as compared to PP.

Figure 7 shows the micrograph of worn surface of PP/PET 70/30 blend. Figure 7a shows the distribution of PET in PP with evidence of removal of PET balls leaving pits at the worn surface. These pits are then in some extent filled by the plastically deformed PP matrix from the surrounding areas under the influence of pressure and temperature during the process of wear. Figure 7b is the magnified view showing the process of wear in PET balls. It is found that very small sized particles of PET (1–2 μm) were removed from the balls during the process of wear.

#### 4. Conclusions

- (I) PP/PET blend shows two-phase morphology in which PET spherical balls are evenly dispersed in the PP matrix.
- (II) Addition of PET in PP improves the wear resistance of PP by reducing wear losses.
- (III) Wear is observed in two stages, the moderate and severe wear. Incorporation of PET in PP helps in increasing the limits of moderate wear towards higher-pressure side.

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