Impact response of injection-moulded polypropylene parts for automotive exteriors

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Summary: Injection moulded polypropylene plates were impact tested at -30 °C at low velocities (≤ 4.4 m/s) and low impact energies (≤ 34 J). Brittle fracture was observed above a certain velocity for plate thicknesses below a certain value. Weld lines, surface texture, paint and more concentrated load induced brittle fracture in more cases.

Introduction

Automotive exterior parts such as bumper covers must fulfil several demanding specifications. This paper deals with the low-velocity low-energy impact response at low temperatures (-30 °C). At cold winter conditions, minor impact events on the bumpers should not result in a brittle fracture (in this abstract we will use the term brittle as a synonym for unstable crack growth). With a given polypropylene compound, the apparent brittleness of a bumper cover, when impacted with a striking object, is related to several coupled factors:

- Loading conditions (temperature, velocity, energy, striker tip geometry)
- Bumper cover details (thickness, paint, surface roughness, local constraints due to cover geometry and assembly)
- Injection moulding process (weld lines, inhomogeneity, anisotropy, residual stresses)

This paper focuses on a series of impact tests of injection moulded plates. This idealised test was used to assess the factors listed above. One aim of this ongoing study is to identify the main factors influencing the impact response, and in particular those leading to brittle fracture at low temperatures. Another aim is to improve material models and data for numerical simulations. Current models for polymers have shortcomings when it comes to predicting unloading (rebounding) response and fracture, and we have addressed some of these challenges in earlier papers [1-3].

Materials and methods

The material in this study is a commercial 20% mineral-filled elastomer-modified polypropylene compound developed for automotive exterior parts. The plate impact tests were performed with an instrumented falling-weight impact tester. The test is similar to ISO 6603-2, but with a lower drop mass, as being used for cold-weather low-velocity impact tests in the automotive industry: The maximum impact (incident) energy in our tests was 34 J at 4.4 m/s. The plates were clamped by a ring with inner diameter 40 mm. Three different strikers were used: 1) a hemispherical striker with diameter 20 mm (this was used if nothing else is stated), 2) a hemispherical striker with diameter 12.6 mm, and 3) a flat striker with diameter 20 mm and a 45° chamfer. Plates with thicknesses in the range 2.0 to 3.9 mm were injection moulded using fan-gated cavities with polished surfaces. In some cases the moulding conditions were varied. Mould inserts were used to assess effects of surface texture (roughness) and weld lines. Some painted plates were also tested. This paper deals with results at -30 °C.

Results and discussion

Effect of plate thickness and impact velocity

Increasing the impact velocity or reducing the plate thickness will increase the maximum stress in the test, at least for deflections up to a certain value. Load-deflection curves for different plate thicknesses tested at 4.4 m/s are shown in Fig. 1. With an impact velocity of 4.4 m/s, the thinnest plates (2.0 mm) fractured in a brittle manner at -30 °C. The 2.4 mm thick plates showed brittle fracture in some tests, ductile response without fracture in other, i.e. it was a borderline case, see Fig. 2 (curves for ø 20 mm hemispherical striker). Plates with thickness 2.9 mm and above did not show brittle fracture. With an impact velocity of 3 m/s, brittle fracture was not observed for any of plate thicknesses. In these cases, the striker rebounded from the plate and produced a dent at the centre.

Effect of injection moulding conditions

Mould temperature, melt temperature and holding pressure were varied for the 2.4 thick plates, i.e. the borderline case mentioned in the section above. Results so far do not show any statistically significant effect of moulding conditions on the probability of getting a brittle response when testing at 4.4 m/s.

Effect of striker geometry

When using a smaller hemispherical striker (ø 12.6 mm) at an impact velocity of 4.4 m/s, all plates except the thickest (3.9 mm) showed brittle fracture. The 3.3 mm thick plate was a borderline case, i.e. some, but not all, tests showed brittle fracture. A flat ø 20 mm striker was also used in some tests of 2.9 and 2.4 mm thick plates. With this striker the plates fractured at quite low deflections, before the load reached a maximum, see Fig. 2a. The peak load was about the same as with the ø 20 mm hemispherical striker.

Effect of weld line

By using an exchangable mould insert, some 3.9 mm thick plates were also filled from two adjacent corners, giving a weld line along the centre of the plate. Some plates were impacted directly on the weld line, and some were impacted ca 10 mm from the weld line. The weld line caused brittle fracture, and typically a 50% reduction in absorbed energy, when testing these plates at 4.4 m/s. Note that these plates with weld line were moulded at the same conditions as the standard plates. The "weld line strength" can often be optimised by adjusting the moulding conditions.

Effect of surface roughness

By using an exchangable mould insert, 2.4 mm thick plates were also made with one side having a surface texture (roughness) typical of a bumper cover. When striking this plate at the textured side (untextured side in tension under the striker), the load-deflection curve was the same as for the standard plates. However, when striking at the reverse side, the plates showed a brittle response with lowered impact energy, both at 3.0 and 4.4 m/s, see Fig. 3. Note that when striking the untextured side, the impact energy was lower at 4.4 m/s than at 3.0 m/s, which was opposite to the trend for the standard plates, even when they were brittle at 4.4 m/s (Fig. 2a).

Effect of painting

Some 2.9 mm thick plates were painted with a commercial paint system (primer, basecoat, clearcoat) and tested at different impact velocities, impacted at the painted side. No cracks were observed after testing at 1 m/s. At 2 and 3 m/s, a circular crack with diameter 40-45 mm (i.e. aligned with the clamping) formed on the impacted side only. At 4.4 m/s this crack ran through the plate. Some load-deflection curves, and a photo of the circular crack, are shown in Fig. 4. Note that this effect of painting was not observed at room temperature.

Fracture types

In this test there could be localisation of tensile strain in one or several regions: 1) at the centre of the plate, on the opposite of the impacted side, 2) on the impacted side, in a circle with diameter similar to that of the of the striker, due to the bending of plate by the striker (at least for some striker geometries and diameters) and 3) around the circumference near the clamp on the impacted side, due to the bending of the plate near the clamp. A crack would typically start in a zone of localised tensile strain, and a shear fracture could initiate after case 2) or 3) above. Different fracture patterns were observed in this study. Two of them are indicated in Figs. 2c and 4b, respectively. The hole in Fig. 2c measured ca 25 mm x 30 mm (in a repeated test ca 28 mm x 36 mm). At one side the hole was close to the clamp. Two fragments were produced in this impact, i.e. there were also two cracks from the centre of the plate out to the boundary crack in Fig. 2c. As seen at the left side of the plate in Fig. 2c, one of these radial cracks also extended out to the boundary of the plate. In this plate, and other plates, the radial cracks ran nearly perpendicular to the (injection moulding) flow direction. The fracture in Fig. 4b is somewhat different, as only a roughly circular "plug" was knocked out of the plate. The crack started at the impacted side, probably in accordance with the strain localisation listed in 3) above.

References

[1] Andreassen, E., Daiyan, H., Grytten, F., Lyngstad, O.V., Gaarder, R.H., Hinrichsen, E.L., Mechanical testing for generating input to numerical simulation of impact response of injection-moulded components, PPS-24 (24th Annual meeting of the Polymer Processing Society), Salerno, Italy, 15.-19. June 2008

[2] Andreassen, E., Persson, A.-M., Nord-Varhaug, K., Brachet, P., Hinrichsen, E.L., Impact fracture toughness of high-density polyethylene – Effects of material parameters and moulding conditions, 5th International conference on fracture of polymers, composites and adhesives, Les Diablerets, Switzerland, 7.-11. September 2008

[3] Glomsaker, T., Andreassen, E., Polanco-Loria, M., Lyngstad, O.V., Gaarder, R.H., Hinrichsen, E.L., Mechanical response of injection-moulded parts at high strain rates, PPS07ea (Polymer Processing Society), Gothenburg, Sweden, 28.-30. August 2007

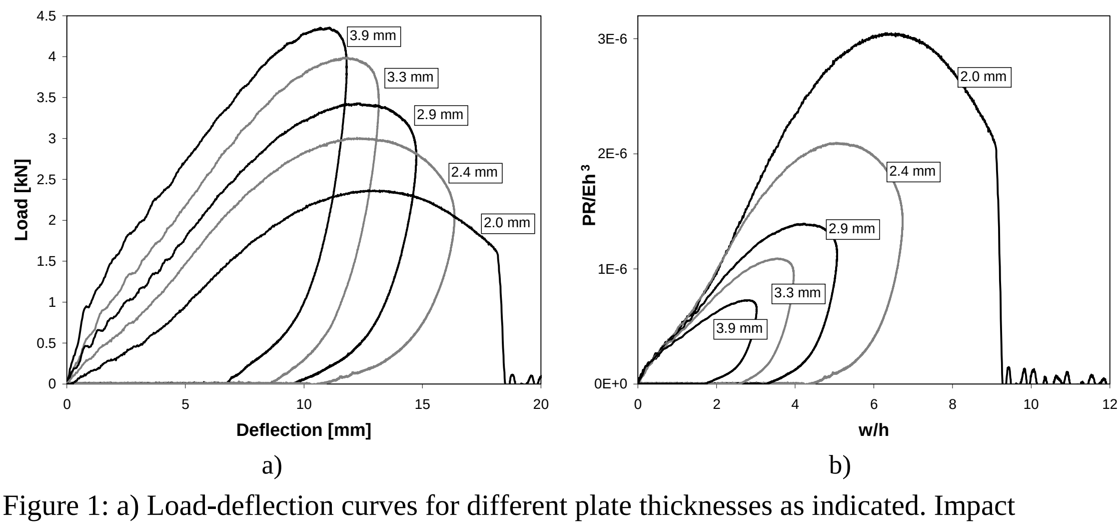
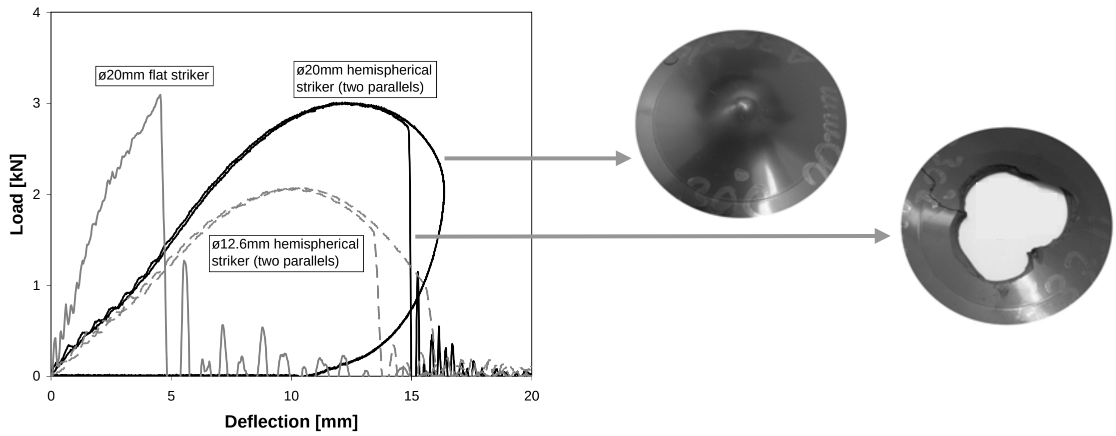
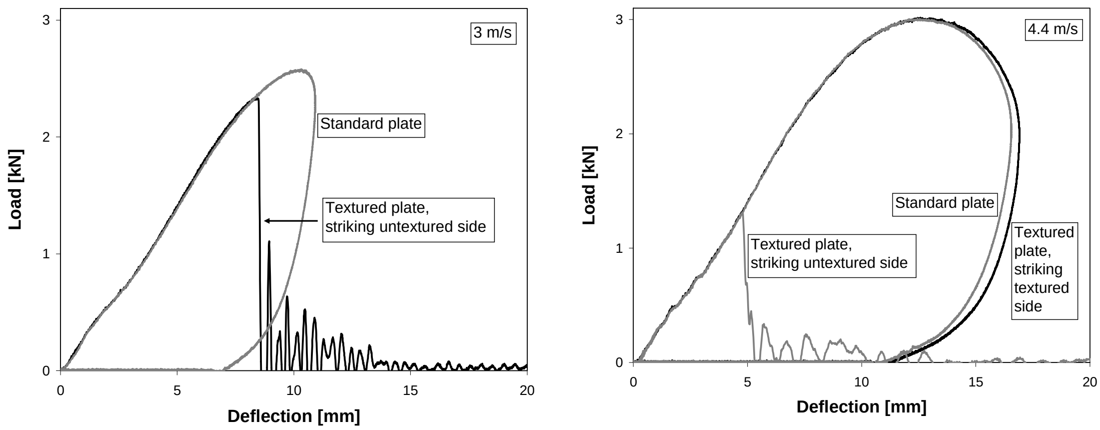


Figure 1: a) Load-deflection curves for different plate thicknesses as indicated. Impact velocity 4.4 m/s and test temperature -30 °C. b) As a), but with dimensionless axis units (P = load, R = clamp radius, E = tensile modulus, h = plate thickness, w = deflection).



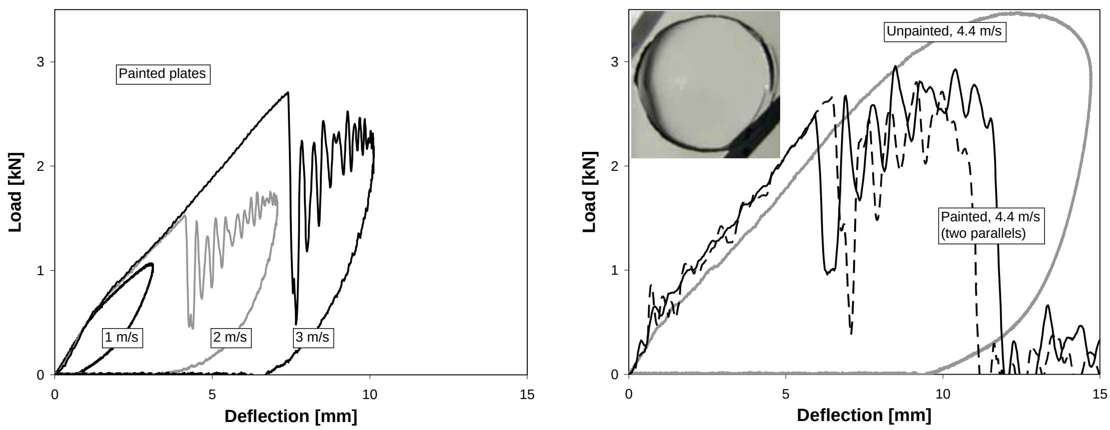
a) b) c)

Figure 2: a) Load-deflection curves for 2.4 mm thick plates, with strikers as indicated.
b) and c) Plates after testing with the ø20mm hemispherical striker. Impact velocity 4.4 m/s and test temperature -30 °C.



a) b)

Figure 3: Load-deflection curves for 2.4 mm thick plates, with and without one textured side, tested at indicated impact velocities. Test temperature -30 °C.



a) b)

Figure 4: Load-deflection curves for 2.9 mm thick painted and unpainted plates, at indicated impact velocities. Test temperature -30 °C. The photo shows the circular crack, running through the plate, for impact speed 4.4 m/s.