# STERILIZATION EFFECTS ON POLYPROPYLENE: TECHNOLOGY AND POLYMER TYPE EFFECTS

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**Abstract:**

Polypropylene, one of the most widely used plastics for packaging applications, is increasingly applied also in the medical area and for pharmaceutical packaging, where the material is mostly sterilized. To gain an overview of sterilizsation effects various polypropylene grades different in structure and additivation were investigated in two forms – cast film and injection molded – and with five different sterilization techniques. Attention was payed to radiation-induced degradation and thermally stimulated post-crystallization, which continue for a long time after the actual sterilization event. Special copolymers can be an interesting solution to embrittlement problems occurring with standard grades, but also special stabilization systems can be used.

## INTRODUCTION

Polypropylene (PP) is one of the most widely used plastics for packaging applications. In a continuously increasing part of this market, especially in the pharmaceutical area, but also in food packaging and especially in medical applications (syringes, pouches, tubes etc.), the material is sterilized in ore or the other way. The use of either heat (steam), radiation (β / electrons or γ) or chemicals (mostly ethylene oxide) affects the mechanical and optical properties, but sometimes also the organoleptics of the material significantly.

From the literature it becomes clear that the changes are quite different. Radiation, where mostly the effect of γ-rays has been investigated in the past, induce chain scission and degradation effects [1,2], resulting in a reduced melt viscosity and severe embrittlement. Parallel to that oxidized phenolic antioxidants results in discoloration; the material becomes yellow. What makes this radical reaction so critical is the fact that it continues for long times after the actual sterilization process, making long-term studies necessary for studying the effects. Various strategies have been published for a reduction of these effects, among which the use of "mobilizing agents" (paraffinic oils [3]) and special stabilizer formulations [4,5] are most relevant.

Steam sterilization, carried out in a temperature range of 120-130°C, results mostly in post-crystallization and physical aging effects of PP [6,7], while the molecular structure is affected much less in this temperature range. It nevertheless causes the material to become more stiff and more brittle. Again, also optical disturbances are possible in the form of significantly increased haze of transparent articles. The post-sterilization changes are significant, but less dramatic than in the irradiation case.

While it is rather clear that chemical sterilizing agents like ethylene oxide have a rather limited effect on PP, little experience exists so far in public about modern alternative sterilization processes like electron (β) irradiation, UV irradiation and the application of ozone. All of these three methods are capable of forming radicals in the polymer, resulting in similar degradation effects as the γ-radiation.

## RESULTS OF SCREENING STUDY

In the years 2001/02 a screening study with different types of polypropylene grades supplied by Borealis – standard and experimental materials – in combination with all frequently applied sterilization technologies was performed at OFI Vienna. The study consisted of two parts, cast film samples and injection molded specimens were tested.

**Cast Film Results**

Three commercial grades from Borealis plus one stabilizer variation of one of these were used in this part of the study (see table 1), for which 200 µm cast films were used. To get a complete picture, five different sterilization techniques – steam (121°C, 20 min), γ-irradiation ($Co^{60}$, 25 kGy), electron irradiation (10 MeV, 25 kGy), ethylene oxide (10% EtOx, 90% $CO_2$, 55-62°C) and UV-C irradiation (~0,3 W/cm², >200 nm) – were used, checking the consequences with mechanical, optical and analytical tests. Molecular degradation effects were investigated with melt viscosity measurements.

| Grade | Type | MFR 230°C/2,16kg g/10min |
|---|---|---|
| RC-P1 | Random Copolymer | 8 |
| RH-P1 | Random-Heterophasic Copolymer | 8 |
| HO-P1 | Homopolymer | 8 |
| RC-VP1 | Random Copolymer | 8 |

**Table 1** – Polymers in first part of screening study (RC-P1 = commercial grade RD208CF, RH-P1 = commercial grade Borsoft™ SD233CF, HO-P1 = commercial grade HD822CF, RC-VP1 - same base polymer as RC-P1 with radiation-resistant stabilization)

Figure 1 gives a good example of the sterilization consequences on the mechanical properties of the PP film for the exemplary case of the ethylene-propylene random copolymer RC-P1: While the modulus is increased – in combination with embrittlement – by the steam sterilization due to recrystallization, the elongation at break drops massively for both irradiation techniques. The effect is even stronger for the γ-radiation sterilization, which actually confirms that β- or electron beam irradiation is less harmful, a fact which was confirmed for all materials. Both ethylene oxide and UV-C irradiation hardly affect the mechanical performance.

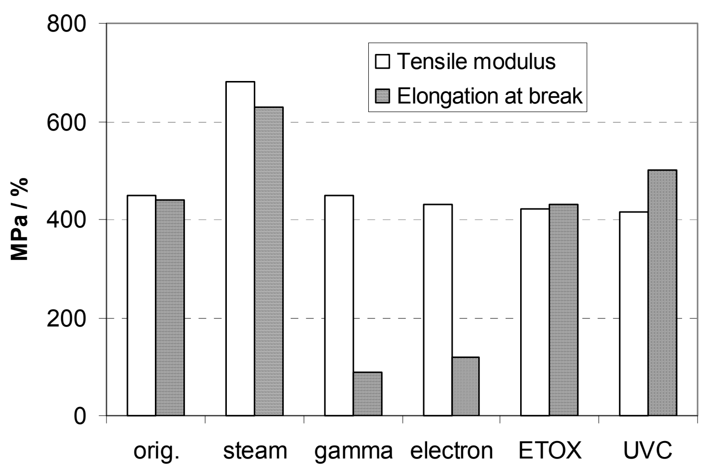


**Figure 1**- Effect of different sterilization techniques on tensile properties of the random copolymer RC-P1

The main reason for this mechanical "breakdown" lies in the chemical degradation of the polymer, which results in a melt viscosity reduction of nearly two orders of magnitude. This is confirmed for all materials, even for the random-heterophasic grade RH-P1, which retains the mechanical properties best in irradiation as compared to all other grades (see Figure 2). This effect has been demonstrated before for heterophasic or elastomer-modified PP grades [8,9] in general. The random-heterophasic copolymer, which is characterised by a very fine phase morphology [10] appears to be especially advantageous due to the improved interaction between the random copolymer matrix and the dispersed elastomer phase, which has been used for filing a patent [11]. The special radiation-resistant addive formulations [4,5] used in the formulation for RC-VP1 improve the situation somewhat in terms of mechanics and molecular weight, but the radiation-induced embrittlement is still serious.

The overall picture does not change if the homopolymer grade HO-P1 is included into these considerations. Another independent problem – again mostly in irradiation sterilization – is the discolouration of PP, seen as an increase of the yellowness index (YI). The stabilization has an important effect here, especially the experimental radiation-resistant formulation reduces this effect significantly in comparison to the standard formulation. Parallel, the development of soluble and volatile components was first checked with the TOC-level (EN 1484), which reflects the water-soluble carbon components in the materials. While the TOC-level is originally already low (< 1 mg/m²d) and even reduced in most sterilization processes for PP, except for the homopolymer HO-P1, which contains a slip-agent. A more detailed analysis of the volatile components with GC-MS demonstrated the relative purity of most of the PP grades as well. "Critical" components were found to be present in sub-ppm quantities only.

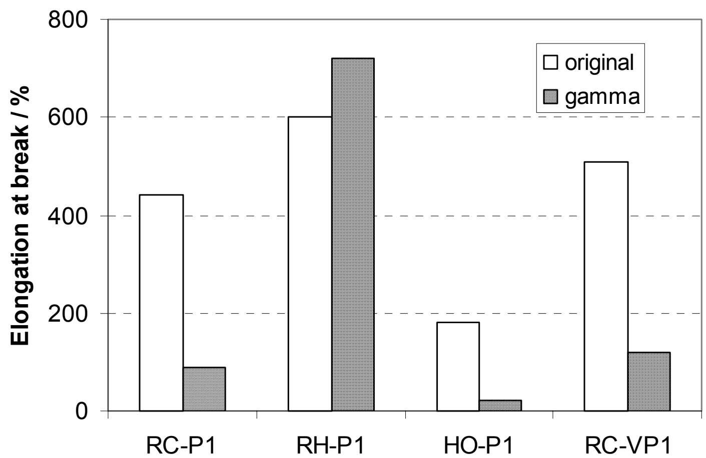


**Figure 2** – Polymer type effect on embrittlement after γ-irradiation

**Injection Molding Results**

A limited number of polymer grades – HO-P2 (a nucleated homopolymer with MFR 8, commercial grade HD810MO), RC-P2 (random copolymer with MFR 20, commercial grade RF830MO) and RC-VP1 (identical to film tests) – were used in this part of the study, in combination with the three most frequently used sterilization techniques: steam, γ-irradiation and electron irradiation (same parameters as above). The samples tested were injection-molded into tensile bars, from which also the specimens for Charpy notched impact testing could be cut. In view of the results from the first phase, all mechanical, optical and analytical investigations were repeated several times up to a period of 150 days after the sterilization event.

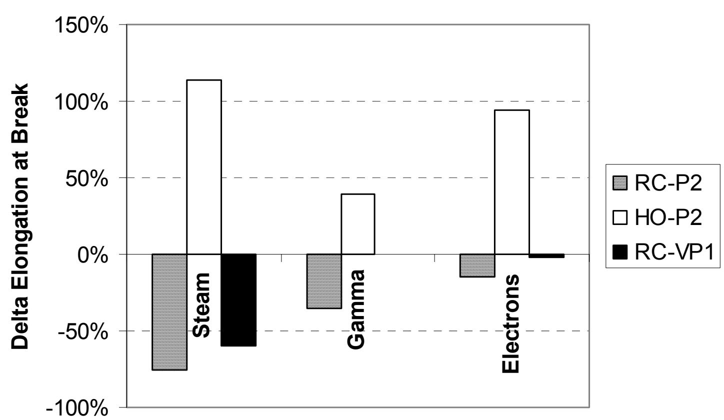


**Figure 3** - Relative change of the elongation at break for molded tensile bars – 47 days after sterilization

If the elongation at break approximately 50 days after the sterilization event is considered as a primary indicator of the sterilization effect (see figure 3), embrittlement effects are most strongly observed for the combination of steam sterilization and RC-P2, while the hompolymer seems to become more ductile in this annealing step. The fact that this is reproduced with the irradiations as well probably results from a heating of the specimens in these processes and must be considered with care anyway, as the $\varepsilon_B$-value of HO-P2 is rather low initially. Even if a direct comparison between the two random copolymers is difficult because of differences in the molecular structure and ethylene content, it appears that the alternative stabilization concept used in case of the RC-VP1 gives some advantage.

A slightly different picture, especially for the case of the homopolymer, is obtained if the fracture work value of the Charpy notched impact test (ISO 179 1eA, +23°C) is regarded. The annealing treatment in steam sterilization improves the toughness for all materials in case of the injection molded specimens, which is only partially in line with the extensive experience gathered in earlier studies [12]. The strongest irradiation-related toughness reduction was found for the homopolymer, which is in line with the rather "normal" stabilizer-package used for this material and the higher crystallinity [13]. All tests related to pharmaceutical requirements – TOC extractables, UV-VIS absorption and cytotoxicity – showed no critical changes after the sterilization processes.

## IRRADIATION EFFECTS ON INJECTION MOULDED PP

More detailed investigations have been carried out earlier in relation to the development of radiation-resistant PP grades at Borealis research. Polymer type, additivation and radiation dose effects were investigated in time series up to 300 days after the sterilization event, which was a $\gamma$-irradiation with $Co^{60}$ / 5 MRad (50 kGy; i.e. twice the intensity used for the screening series outlined before). Injection-molded tensile bars were used, from which also the specimens for Charpy notched impact testing could be cut. Only part of the results will be presented here, demonstrating polymer and additivation effects with four grades as listed in table 2.

| **Grade** | **Type** | **MFR 230°C/2,16kg g/10min** |
|---|---|---|
| HO-VP1 | Homopolymer | 20 |
| HO-VP2 | Homopolymer * | 20 |
| RH-VP1 | Random-Heterophasic Copolymer 1 | 8 |
| RH-VP2 | Random-Heterophasic Copolymer 2** | 8 |

**Table 2** – Polymers in radiation effect study (* - same polymer as HO-VP1 with radiation-resistant stabilization, ** - same polymer as RH-VP1 with radiation-resistant stabilization)

Figure 4 clearly demonstrates the dominating importance of the polymer structure, again showing the superior resistance of random-heterophasic copolymers to radiation-induced degradation effects. The sole use of a radiation-resistant additive formulation (which was different from the formulation used in the OFI screening study outlined before) was not sufficient to drastically reduce the embrittlement of the homopolymer, but it gave positive effects in terms of discoloration (i.e. a reduced increase of the yellowness index) and impact strength.

A possible explanation for the general superiority of heterophasic systems lies in the different reaction of the PP matrix and the dispersed elastomeric phase to radical reactions, which can also be seen in visbreaking (peroxide-controlled degradation) of heterophasic copolymers [14]. Random-heterophasic systems have the additional advantage of a very fine phase structure resulting from viscosity adaption and improved compatibility between the phases, resulting in improved transparency.

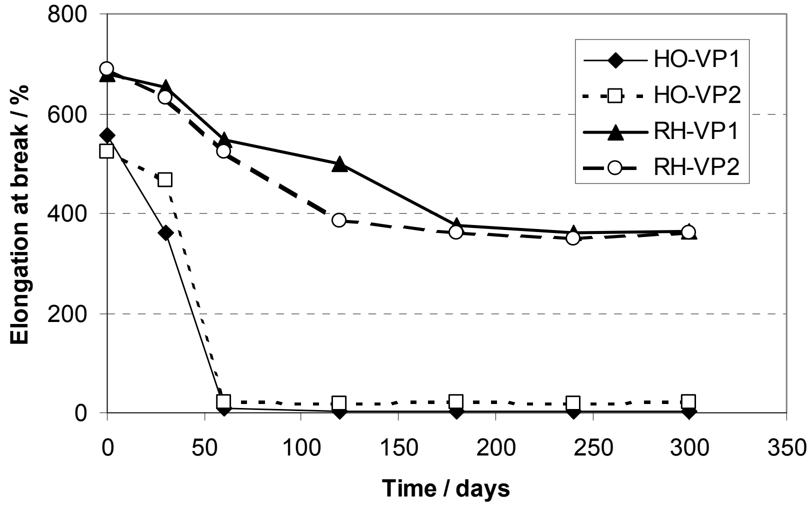


**Figure 4** – Time dependent decrease of the elongation at break after γ-irradiation for four different PP grades

## STEAM STERILISATION EFFECTS ON PP CAST FILM

Extensive work on post-crystallization and physical aging of PP was done at Borealis reasearch in connection with an EU-funded project on crystallization effects in polymer processing and have been mostly reported before [7,12]. In most cases also a sterilization-related annealing step of 121°C / 0,5 h was tested, with successive measurements of mechanical and optical properties for a period up to 330 days. An interesting aspect of these studies was the effect of processing conditions, especially in the case of cast films [15], especially the pronounced effect of the ”quenching”-type solidification. As outlined before, the use of very cold chill rolls leads to a suppression of crystallization (also seen in the group of Piccarolo [16]), resulting in stronger property changes in the post-processing phase.

In the cast-film part of these studies three structurally different PP grades (all with a standard additivation, see table 3) were tested after extrusion of 50 µm films on a 50 mm Battenfeld single screw extruder equipped with a 1000 mm wide slit die in a thickness of 50 µm and trimmed to a width of 800 mm. The processing conditions were varied by changing the temperatures of the chill rolls; only results from “cold” rolls (15-25°C) will be discussed here. Tensile tests, penetration tests (+23°C, Dynatest) and haze tests were done in time series on the original (non-annealed) and the “sterilized” (annealed) films.

| Grade | Type | MFR 230°C/2,16kg g/10min |
|---|---|---|
| HO-P3 | HCPP Homopolymer | 8 |
| RC-P1 | Random Copolymer | 8 |
| HC-VP1 | Heterophasic Copolymer | 4 |

**Table 3** – Polymers in cast-film part of ageing study (HO-P3 – high-crystallinity PP with increased isotacticity, commercial grade Bormod™ HD905CF; RC-P1 – as before; HC-VP1 – experimental grade)

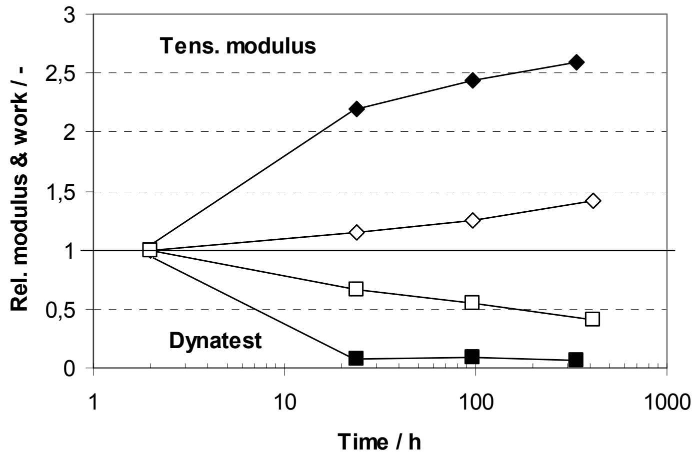


**Figure 5** – Relative development of modulus and penetration work ($E_{total}$ from Dynatest) for RC-P1 cast films (50 µm), open symbols – original samples, full symbols – sterilized samples (121°C / 0,5 h)

To get a general view at the development of film mechanics in ageing and annealing, figure 5 summarizes the modulus and penetration results for the random copolymer RC-P1. A logarithmic time scale was used as in earlier presentations [12] to underline the ongoing mechanical changes even long times after processing. The sterilization step increases the crystallinity of the films significantly for all materials, resulting in a modulus and haze increase together with significant embrittlement. Table 4 summarizes the mechanical consequences of room-temperature aging and clearly shows that only in case of the heterophasic copolymer the original impact strength can be retained in a significant amount.

| Grade | Tensile modulus | | | $E_{total}$ Dynatest | | |
|---|---|---|---|---|---|---|
| | original | aged | sterilized | original | aged | sterilized |
| | MPa | MPa | MPa | J | J | J |
| HO-P3 | 833 | 1137 | 1568 | 0,10 | 0,07 | 0,04 |
| RC-P1 | 246 | 348 | 637 | 2,07 | 1,28 | 0,28 |
| HC-VP1 | 278 | 409 | 840 | 2,52 | 1,42 | 0,94 |

**Table 4** – Cast film mechanics of PP-grades in the aging study; "original" values ~24 h after processing, "aged" 336 days after processing, "sterilized" 336 days after steam sterilization (121°C / 0,5 h)

## CONCLUSIONS

Both the applied sterilization technology and the polymer type in connection with the stabilizer formulation used strongly affect the changes in composition, mechanics and optics resulting from a sterilization step. The different effects of the two mostly used techniques – steam and γ-irradiation – are related to the mechanisms induced: Degradation for the irradiation and post-crystallization for steam. Special copolymers are the most interesting solution to embrittlement problems ocurring with standard grades, but also special stabilization systems also can give some advantage, especially for reducing the discoloration problems.

**ACKNOWLEDGEMENTS**

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**References**

1 – Martakis, N., Niaouniakis, M., and Pissimissis, D., "Gamma-sterilization effects and influence of the molecular weight distribution on the postirradiation resistance of polypropylene for medical devices", J.Appl.Polym.Sci. 51(2), pp. 313-328 (1994)
2 – Thorat, H.B., Prabhu, C.S., Suresh, K.K., and Pandya, M.V., "γ-Ray-Induced Degradation in Ethylene-Propylene Copolymer", J.Appl.Polym.Sci., 59 (11), pp. 1769-1773 (1996)
3 – Williams, J.L., Dunn, T.S. and Stannett, V.T., "Mobility as a Mechanism for Radiation Stabilization of Polypropylene", Radiat.Phys.Chem., 19 (4), pp. 291-296 (1982)
4 – Klemchuk, P.P., "Protecting Polymers Against Damage from Gamma Radiation", Radiat.Phys.Chem., 41 (1/2), pp. 165-172 (1993)
5 – Moore, E.P, "Polypropylene compositions resistant to radiochemical sterilization", US 4888369 for Himont Inc., USA
6 – O'Kane, W., Young, R.J., and Ryan, A.J., "The Effect of Annealing on the Structure and Properties of Isotactic Polypropylene Films", J.Macromol.Sci.-Phys., B34 (4), pp. 427-458 (1995)
7 – Fiebig, J., Gahleitner, M., Paulik, C., and Wolfschwenger, J., "Ageing of Polypropylene: Processes and Consequences", Polym.Testing, 18 (4), pp. 257-266 (1999)
8 – Sterzynski, T. and Thomas, M., "Gamma Radiation Induced Changes in the Structure and Properties of Copolymers of Propylene", J.Macromol.Sci.-Phys. B34 (1&2), pp. 119-135 (1995)
9 – Portnoy, R.C., "Clear, Radiation Sterilizable, Autoclavable Blends Based on Metallocene Catalyzed Propylene Homopolymer", SPE ANTEC, 75 (Vol. 3), pp. 3011-3015 (1999)
10 – Starke, J.U., Michler, G.H., Grellmann, W., Seidler, S., Gahleitner, M., Fiebig, J. and Nezbedova, E., "Fracture Toughness of Polypropylene Copolymers: Influence of Interparticle Distance and Temperature", Polymer, 39(1) pp. 75-82 (1998)
11 – Bernreitner, K. and Wolfschwenger, J., "Use of thermoplastic elastomers for improving the stability of polyolefins to ionizing radiation", EP 857755 B1 for Borealis GmbH., Austria
12 – Gahleitner, M., Fiebig, J., Wolfschwenger, J., Dreiling, G. and Paulik, C., "Post-Crystallization and Physical Ageing of Polypropylene: Material and Processing Effects", J.Macromol.Sci.B – Phys., B41 (4-6), pp. 833-849 (2002)
13 – Kadir, Z.A., Yoshii, F., Makuuchi, K. and Ishigaki, I., "Durability of radiation-sterilized polymers: 12. The effects of nucleatioting agent on the oxidative degradation of polypropylene", Polymer, 30 (8), pp. 1425-1432 (1989)
14 – Gahleitner, M., Paulik, C., Bernreitner, K. and Neißl, W., "Degradation and Crosslinking Effects in High-Impact Polypropylene Copolymers", Proc. of PPS America Meeting, Toronto/CD, pp. 49-50 (1998)
15 – Macauley, N.J., Harkin-Jones, E.M.A. and Murphy, W.R., "The Influence of Nucleating Agents on the Extrusion and Thermoforming of Polypropylene", Polym.Eng.Sci. 38 (4), pp. 662-673 (1998)
16 - Gerardi, F., Piccarolo, S., Martorana, A. and Sapoundjieva, D., "Study of the long-period changes in samples of isotactic poly(propylene) obtained by quenching from the melt and subsequent annealing at different temperatures", Macromol.Chem.Phys., 198 (12), pp. 3979-3985 (1997)

# Sterilization Effects on Polypropylene: Technology and Polymer Type Effects

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# Content

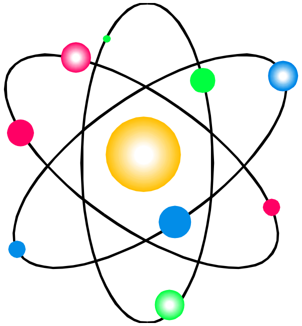
- Why did we do it ?
- How do methods & polymers affect the sterilization results ?
- What happens in detail with $\gamma$-irradiation ?
- What happens in detail with steam ?
- Which conclusions can be drawn ?

# Why did we do it ?

- Polypropylene (PP) increasingly used for medical applications
- Sterilization used also in other application areas of PP (food & pharmaceutical packaging)
- Use of heat (steam), radiation ($\beta$ / electrons or $\gamma$) or chemicals (mostly ethylene oxide) affects the mechanics, optics & organoleptics significantly
- Different combination of polymer & stabilizer system might be necessary for different methods

# Different methods - different effects ...

- Radiation ($\beta$ / electrons or $\gamma$) induces chain scission process (via radicals) resulting in degradation, phenolic antioxidants oxidized in this process lead to discoloration
- Steam sterilization (temperature range of 120-130°C) results mostly in post-crystallization and physical aging effects of PP - embrittlement & haze increase
- Ethylene oxide sterilization least damaging
- Effects largely unknown for alternative methods (e.g. UV-C)



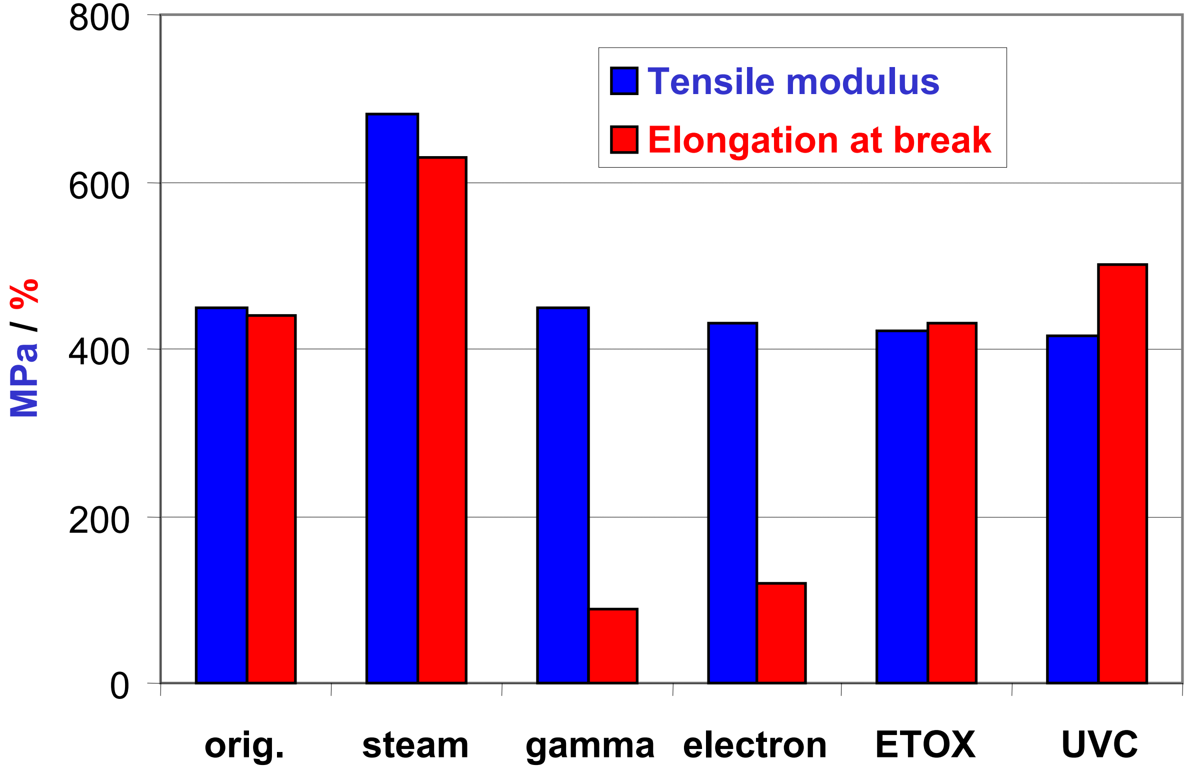
# Screening study at OFI - Cast films (1/3)

- 4 different PP grades (see table) in cast films (200 µm)
- 5 different sterilization techniques – steam (121°C, 20 min), $\gamma$-irradiation ($Co^{60}$, 25 kGy), electron irradiation (10 MeV, 25 kGy), ethylene oxide (10% EtOx, 90% $CO_2$, 55-62°C) and UV-C irradiation (~0,3 W/cm², >200 nm)
- mechanical, optical and analytical tests done

| Grade | Type | MFR 230°C/2,16kg |
|---|---|---|
| | | g/10min |
| **RC-P1** | Random Copolymer | 8 |
| **RH-P1** | Random-Heterophasic Copolymer | 8 |
| **HO-P1** | Homopolymer | 8 |
| **RC-VP1** | Random copolymer* | 8 |

* - same polymer as RC-P1, radiation-resistant stabilizer package

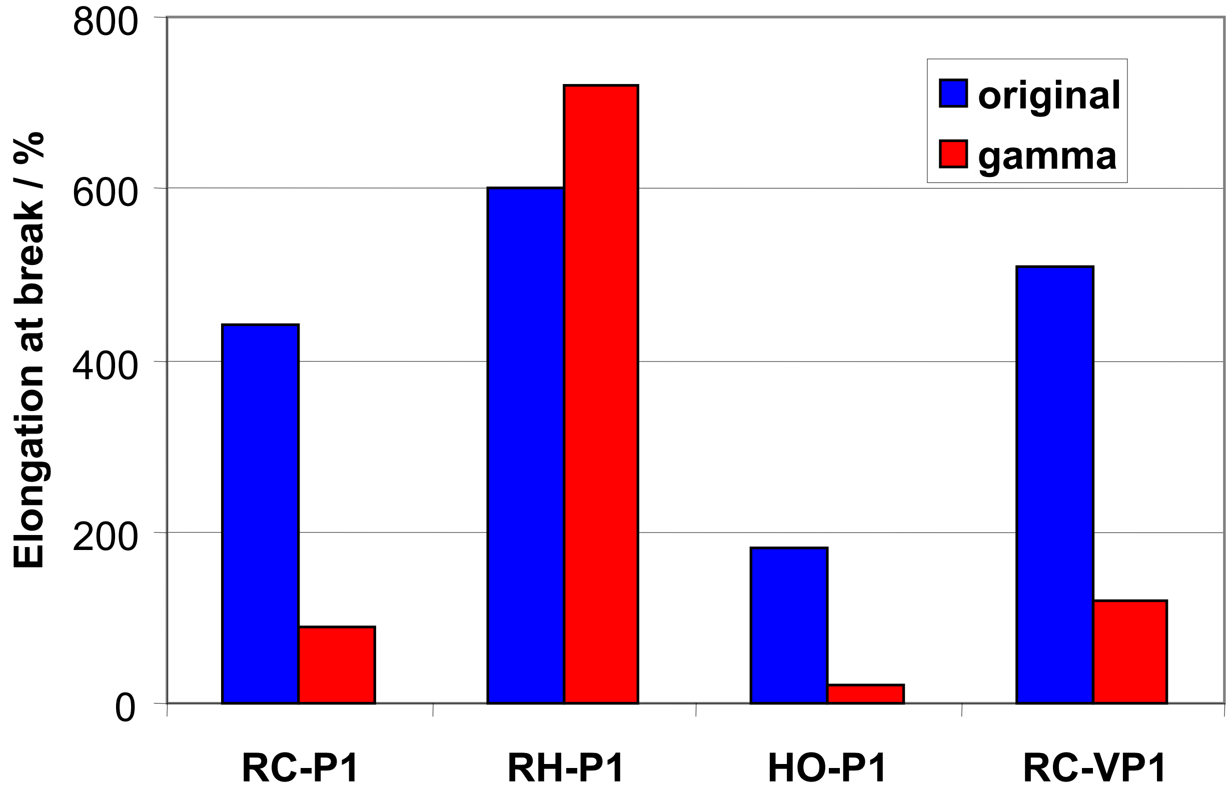
# Screening study at OFI - Cast films (2/3)




**Effect of different sterilization techniques on tensile properties of the random copolymer RC-P1 (EP random copolymer))**

- modulus increase & embrittlement for steam sterilization
- massive drop in $\varepsilon_B$ for irradiation techniques (slightly less for $\beta$)

# Screening study at OFI - Cast films (3/3)




**Polymer type effect on embrittlement after $\gamma$-irradiation**

- random-heterophasic grade retains mechanical properties best in irradiation
- radiation-resistant additives improve the situation slightly

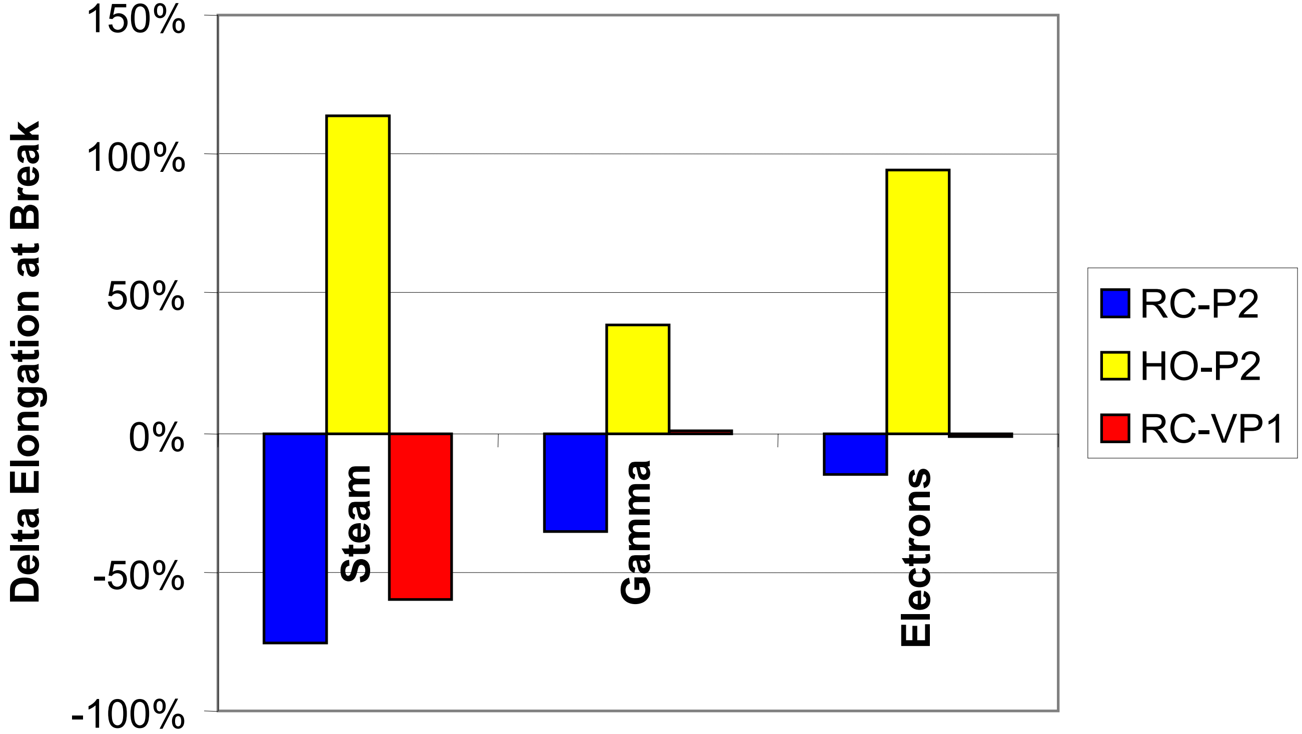
# Screening study at OFI - IM specimens (1/3)

- **3 different PP grades (see table) in injection-molded tensile bars**
- **3 different sterilization techniques – steam (121°C, 20 min), $\gamma$-irradiation ($Co^{60}$, 25 kGy) and electron irradiation (10 MeV, 25 kGy)**
- **mechanical, optical and analytical tests done - time series after sterilization event (up to 150 days)**

| Grade | Type | MFR 230°C/2,16kg |
|---|---|---|
| | | g/10min |
| **RC-P2** | Random Copolymer (nucleated) | 20 |
| **HO-P2** | Homopolymer* | 8 |
| **RC-VP1** | Random copolymer** | 8 |

*** - radiation-resistant stabilizer package**
**** - identical to cast film tests**

# Screening study at OFI - IM specimens (2/3)

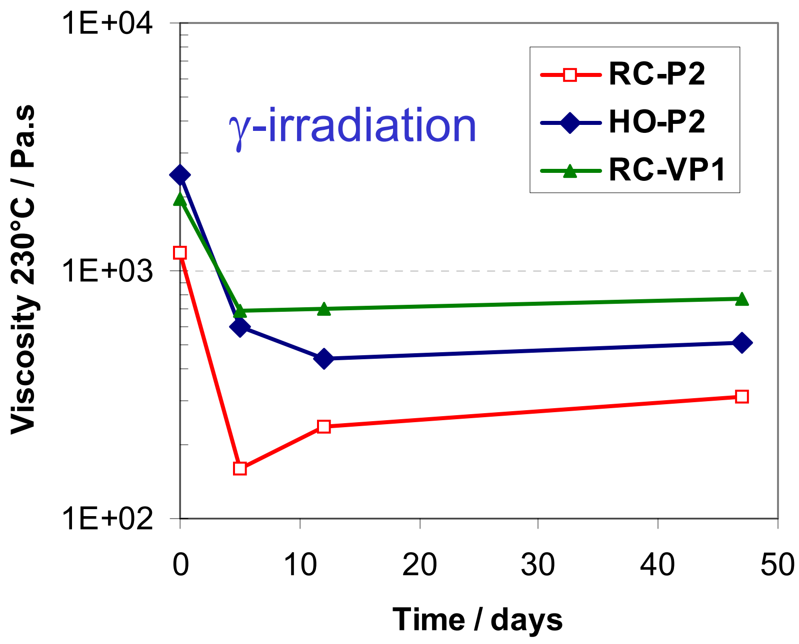


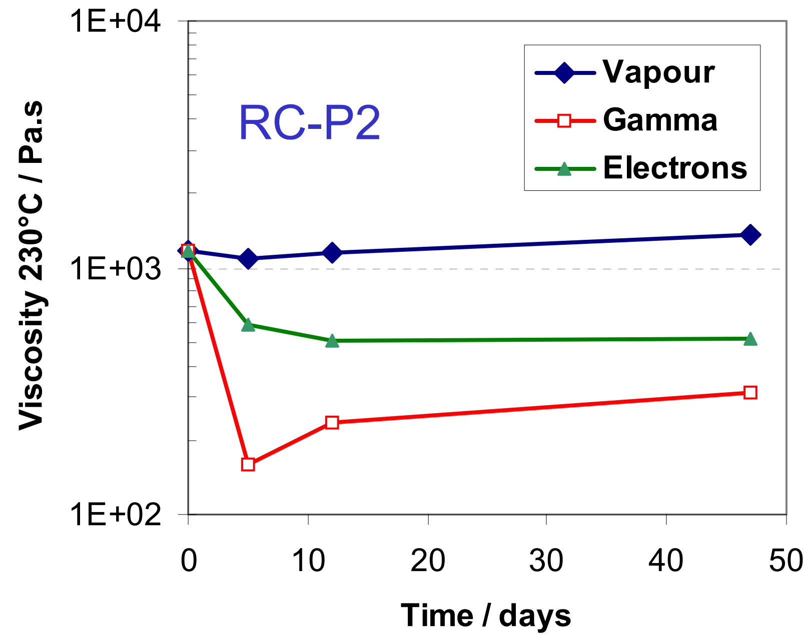

**Relative change of the elongation at break (after 47 d)**

- strongest embrittlement for the combination of steam sterilization and random copolymer (better performance of lower MFR grade in irradiation)
- $\varepsilon_B$-increase for homopolymer rather irrelevant because of low start level

# Screening study at OFI - IM specimens (3/3)

**Differences in degradation effects (monitored via melt viscosity, dynamic test) between sterilization techniques ...**




**… and polymer / stabilizer types are reflected in time-dependent embrittlement (mostly for the two irradiation techniques)**

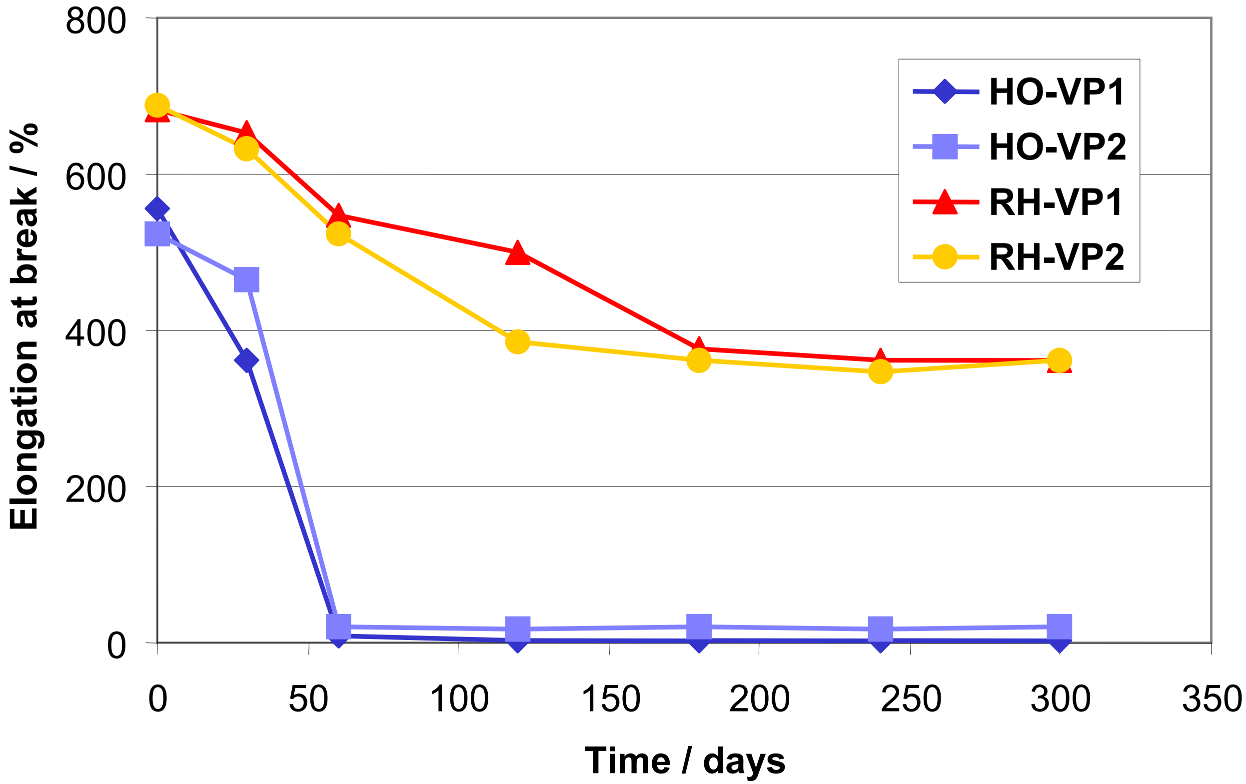
# $\gamma$-irradiation effects in detail (1/3)

- 4 different experimental PP grades (see table) in injection-molded tensile bars
- sterilization technique $\gamma$-irradiation ($Co^{60}$, 50 kGy) - twice as high as in screening series!
- mechanical, optical and analytical tests done - time series after sterilization event (up to 300 days)

| Grade | Type | MFR 230°C/2,16kg g/10min |
|---|---|---|
| HO-VP1 | Homopolymer | 20 |
| HO-VP2 | Homopolymer * | 20 |
| RH-VP1 | Random-Heterophasic Copolymer 1 | 8 |
| RH-VP2 | Random-Heterophasic Copolymer 2** | 8 |

* - same polymer as HO-VP1 with radiation-resistant stabilizer package
** - same polymer as RH-VP1 with radiation-resistant stabilizer package

# γ-irradiation effects in detail (2/3)



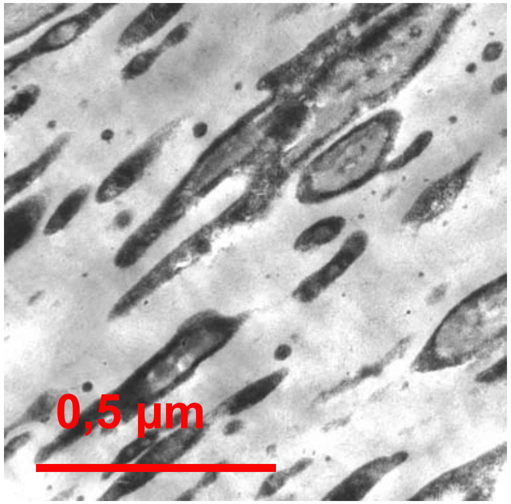

**Time dependent decrease of the elongation at break after irradiation**

- strongest embrittlement for homopolymers within 50 days
- random-heterophasic grades retain >50% of their toughness

# $\gamma$-irradiation effects in detail (3/3)

**Additional findings on $\gamma$-irradiation:**

- ➔ **no critical increase of TOC-level in any case**
- ➔ **radiation-resistant stabilizer packages not sufficient for avoiding embrittlement, but reducing discoloration**
- ➔ **general superiority of heterophasic systems lies in the different reaction of the PP matrix and the dispersed elastomeric phase to radical reactions**




*Phase morphology (TEM after $RuO_4$ staining) of random-heterophasic copolymer (RH-P1 from screening series)*

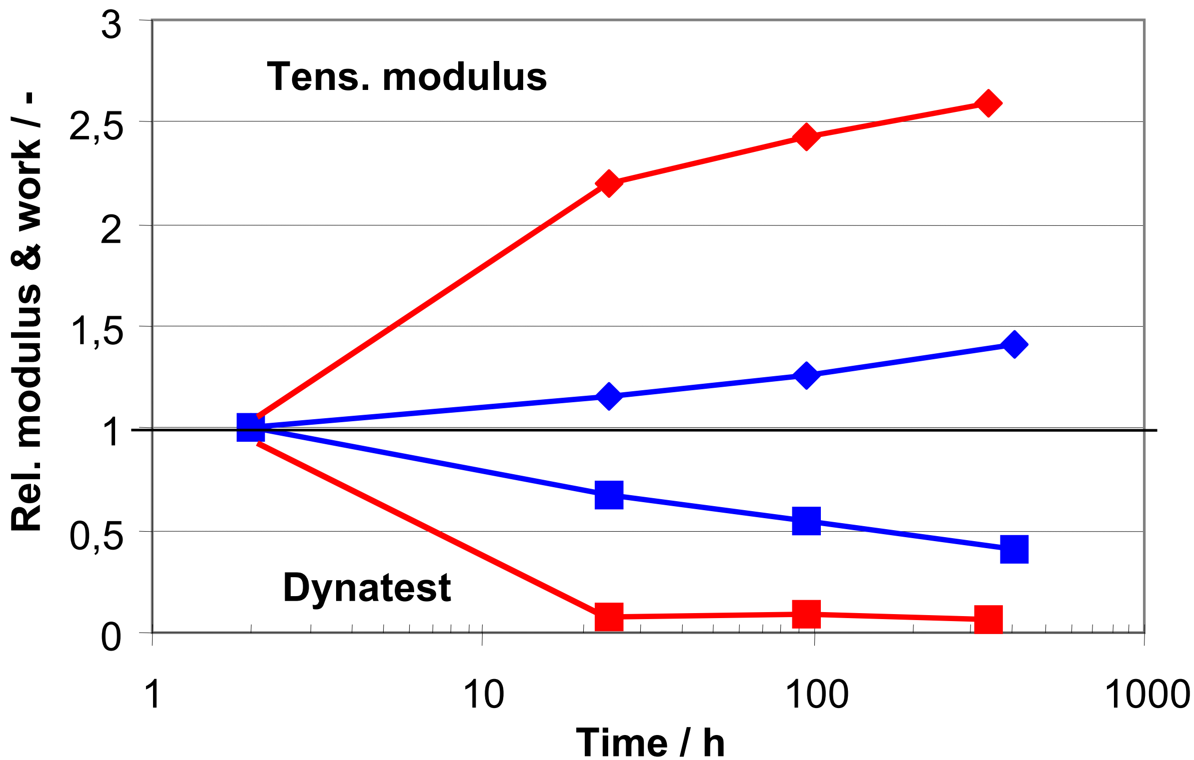
# Steam sterilization effects in detail (1/3)

- 3 different experimental PP grades (see table) in 50 µm cast films (cold chill-roll)
- sterilization technique steam (121°C, 20 min - among other annealing conditions)
- mechanical, optical and analytical tests done - time series after sterilization event (up to 330 days)

| Grade | Type | MFR 230°C/2,16kg |
|---|---|---|
| | | g/10min |
| HO-P3 | HCPP Homopolymer* | 8 |
| RC-P1 | Random Copolymer** | 8 |
| HC-VP1 | Heterophasic Copolymer | 4 |

* - high-crystallinity grade with increased isotacticity
** - identical to screening series cast film

# Steam sterilization effects in detail (2/3)




**Relative development of modulus and penetration work ($E_{total}$ from Dynatest) after steam sterilization for RC-P1**

- sterilization step increases film crystallinity significantly for all grades
- modulus and haze increase together with significant embrittlement

# Steam sterilization effects in detail (3/3)

**Additional findings on steam sterilization:**

- ➔ **no critical increase of TOC-level in any case, but discoloration and haze increase can be significant**
- ➔ **special stabilizer packages rather useless**
- ➔ **only in case of the heterophasic copolymer the original impact strength can be retained in a significant amount**

| Grade | Tens. mod. | | | $E_{total}$ | | |
|---|---|---|---|---|---|---|
| | original | aged | sterilized | original | aged | sterilized |
| | MPa | MPa | MPa | J | J | J |
| HO-P3 | 833 | 1137 | 1568 | 0,1 | 0,07 | 0,04 |
| RC-P1 | 246 | 348 | 637 | 2,07 | 1,28 | 0,28 |
| HC-VP1 | 278 | 409 | 840 | 2,52 | 1,42 | 0,94 |

Cast film mechanics of PP-grades in the aging study
"original" values ~24 h after processing, "aged" 336 days after processing, "sterilized" 336 days after steam sterilization (121°C / 0,5 h)

# Conclusions

- Applied sterilization technique and polymer / stabilizer type strongly affect changes in composition, mechanics and optics resulting from sterilization
- Effects of two mostly used techniques - steam and $\gamma$-irradiation - related induced mechanisms: Degradation for irradiation and post-crystallization for steam
- Special copolymers are the most interesting solution to embrittlement problems occurring with standard grades
- Special stabilization systems can give some advantage for reducing discoloration

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