

# Closed-Loop Recycling of Postused Garden Chairs Based on PP Using the Restabilization Technique. I. Evaluation of Processing Parameters

C. N. Kartalis,<sup>1</sup> C. D. Papaspyrides,<sup>1</sup> R. Pfaendner<sup>2</sup>

<sup>1</sup>Laboratory of Polymer Technology, Department of Chemical Engineering, National Technical University of Athens, Zographou, Athens 157 80, Greece

<sup>2</sup>Ciba Spezialitaetenchemie Lampertheim GmbH, Chemiestraße, D-68623 Lampertheim, Germany

Received 15 June 2001; accepted 7 January 2002

**ABSTRACT:** A remelting–restabilization technique was applied to evaluate the closed-loop recycling of postused, white pigmented, garden chairs made from CaCO<sub>3</sub>-filled polypropylene (PP). Analysis of the randomly collected postused chairs showed only an insufficient quantity of residual active stabilizers. Different stabilization systems in selected concentrations were employed to investigate the optimum restabilization recipe for eliminating degradation effects during reprocessing. For monitoring the processing stability of the restabilized and nonrestabilized material a multiple extrusion procedure at two different reprocessing tempera-

tures was performed. Furthermore, a repigmentation step was applied to investigate the role of the additional pigment on the processing stability of the recycled product. Finally, mechanical tests were carried out, for studying further the effect of restabilization on the mechanical performance of the recycled material. The results lead to the conclusion that restabilization for quality improvement of postused filled PP chair material during reprocessing is permitting its reuse in the original application. © 2002 Wiley Periodicals, Inc. *J Appl Polym Sci* 86: 2472–2485, 2002

## INTRODUCTION

In terms of economics, the success of mechanical recycling strongly depends on whether virgin material can be substituted by recycle fulfilling the same properties as the virgin plastic. In the past few years, the prerequisite of upgrading recyclates has become the key issue for market acceptance.<sup>1–4</sup>

Usually, postused plastics, even from well-defined applications, cannot be reused in the form they were collected because physical predamage, structural inhomogeneities, and residual impurities are present, strongly affecting the recyclates' quality. Already during their previous processing steps and service life plastics are subjected to undesirable chemical reactions, mainly caused by oxidation and photooxidation, which lead to irreversible changes in the polymer structure, negatively affecting the physical and mechanical properties of the polymer and the corresponding recycle. In addition, predamaged structures of recyclates are much more sensitive to further oxidation than the corresponding virgin materials, because they contain groups that can enhance or initiate

thermo- or photo-oxidation. In other words, reprocessing of recyclates would lead to further degradation of the quality of the recycled material, unless appropriate protection is applied.<sup>2–6</sup>

In the case of polypropylene (PP), the recycled polymer suffers from severe molecular weight degradation in course of reprocessing. This behavior is correlated with the well-known chain scission mechanism occurring during reprocessing of polymers with branched alkanes.<sup>7–10</sup> In particular, during reprocessing the polymer melt is exposed to high shear forces and high temperatures that result in C—C chain scission phenomena along the polymer structure. The latter leads to chain length reduction, to molecular weight degradation and consequently to negative modifications in the basic material properties of the reprocessed grade.<sup>9,10</sup> In practice, oxidative degradation during reprocessing negatively affects the rheological properties of the recycled material as well as typical mechanical properties, such as elongation at break, tensile strength, and flexibility.<sup>11,12</sup>

Restabilization, probably the most effective approach to improving the quality of recyclates, can compensate or at least reduce the aforementioned deficiencies to such an extent that the required processing and long-term stability is ensured. As a result, the economical and the ecological value of the recycled end product is increased.<sup>2–6,13–16</sup>

Correspondence to: C. D. Papaspyrides (kp@softlab.ece.ntua.gr).

However, dealing with postused plastics containing a significant high portion of foreign matter, such as other polymers or impurities from first service life, it is not sufficient to simply maintain the physical properties by the addition of stabilizers. Fillers act in a similar way as a kind of "intentional foreign matter." Therefore, negative filler effects should also be eliminated for protecting the quality of the recycled product as well as to ensure its long-term thermal and light stability.<sup>4,6</sup> For instance, it is known that inorganic fillers negatively affect the stability of the polymer matrix by adsorbing active stabilizers on the surface, limiting, in this way their stabilization action. Only by the addition of especially developed systems that play the role of filler deactivator can the stability of the polymeric material be considerably improved.<sup>5-7,17</sup>

Garden plastic chairs are an example of a very well-defined recycle stream, that can be easily collected in big quantities, especially in the Mediterranean countries. The 100% reuse of the postused chair material is strongly favorable from an ecological point of view, but this can be feasible only through its quality improvement, so that it can satisfy the requirements of the original application. Usually plastic garden chairs are based on polypropylene matrix, containing a significant quantity of an inorganic filler. The use of this kind of filler considerably reduces the cost of the final product but also increases its stiffness, which is essential in this type of application. However, the presence of the filler also reduces the stability of the polymeric matrix during processing or during use. On the one hand, the filler particles from natural sources contain impurities such as iron or manganese ions that can catalyze the autoxidation reaction of the polymer chain. On the other hand, adsorption, i.e., interactions of the polar stabilizer molecules with polar filler groups on the surface, can reduce the activity of antioxidants and light stabilizers.<sup>6,17</sup> As already mentioned, stabilization improvement in this type of material requires not only the addition of a sufficient content of antioxidants and light stabilizers but also the presence of a filler deactivator typically based on epoxy resins that can block the "consumption" of the aforementioned additives due to the filler porosity.<sup>6</sup>

In the literature, there are very few examples of quality improvement of PP-filled recyclates using the restabilization technique. In a very recent study, Ciba Specialty Chemicals Ltd. examined the possibility of upgrading postused stadium seats made from PP filled with 30% talc, through restabilization. The results proved that the addition of only typical stabilizing agents cannot effectively improve the thermal stability of the recycle due to the inorganic filler negative effect. On the other hand, the addition of a typical filler deactivator proved to be essential for improving the long-term stability of the recycled product.<sup>6</sup> In another study by Ciba Specialty Chemicals Ltd, the

same filler deactivator proved to be very effective, by eliminating the negative effect of residual inks and pigments in the mechanical performance of car bumpers made of PP/EPDM.<sup>4,6</sup>

The aim of the work presented here and further studies is to investigate for the first time in a detailed way the behavior of recyclates containing fillers, and to provide solutions to reuse the recycle mechanically. More specific, the upgrading of postused, white pigmented garden chairs made from filled polypropylene through the remelting-restabilization technique to prove closed-loop recycling possibilities was studied. Different stabilization systems in selected concentrations were employed to develop the optimum restabilization recipe for eliminating degradation effects during reprocessing. To evaluate the effect of the restabilization applied, the processing stability at two different reprocessing temperatures and the mechanical performance of the recycled material are studied. In particular, multiple extrusion cycles are performed to correlate the reprocessing effect with the melt flow rate, while tensile and tensile impact tests are carried out for estimating the mechanical performance of the recycled material.

## EXPERIMENTAL

### Materials

#### Starting material

Postused, white pigmented garden chairs manufactured from filled PP was used for this study. An amount of 100 kg was randomly collected from a local landfill in Greece. The chairs were carefully washed, dried, and then they were shredded and stored.

The chair material contained 15% CaCO<sub>3</sub> on average, while the basic pigment was TiO<sub>2</sub>. The age of the postused chairs collected was estimated between 3 to 5 years. Analysis of the homogenized chairs material gave only a small quantity of residual active stabilizers in the range of: (a) approximately 350 ppm phenolic type primary antioxidants, (b) no active phosphate-based secondary antioxidants, and (c) no active epoxide as filler deactivator.

#### Restabilization systems

Different stabilization additives from Ciba Specialty Chemicals Ltd. in selected concentrations were employed to develop the optimum restabilization recipe for eliminating degradation effects. In addition to processing stabilizers a sufficient content of light stabilizers was employed, due to the outdoors nature of the current application. The three restabilization systems employed in this study were chosen with the aim to reuse the material again in the form of garden chairs:

1. Recyclostab 451®: stabilization system based on different types of antioxidants and costabilizers specifically developed to offer processing stability and long-term thermal protection for recycled plastics, especially for polypropylene and polyolefin blends.
2. Recyclosorb 550®: stabilization system specifically developed for light stabilization of recycled plastics, but also it provides basic processing and heat stability to polyolefin recyclates. It is a mixture of antioxidants, costabilizers, and light stabilizers.
3. Recycloblend 660®: stabilization system specifically developed for desensibilization of polyolefins against the negative influences of impurities, such as paint or ink residues during processing and heat aging. Furthermore, it acts as a deactivator for compounds such as carbon black, fillers, etc. It consists of antioxidants, co-additives and selected oxirane compounds as reactive agents in a specific ratio.
6. **R6**: remelting of restabilized material using 0.2% w/w Recyclosorb 550® and 0.2% w/w Recycloblend 660®
7. **R7**: remelting of restabilized material using 0.2% w/w Recyclosorb 550® and 0.5% w/w Recycloblend 660®
8. **R8**: remelting of restabilized material using 0.4% w/w Recyclosorb 550® and 0.5% w/w Recycloblend 660®
9. **R9**: remelting of restabilized material using 0.4% w/w Recyclosorb 550® and 1% w/w Recycloblend 660®

For each of the aforementioned qualities five successive extrusion cycles were performed using a Brabender Plasti-Corder PLE 330, single-screw laboratory extruder. The screw length was 500 mm (L) and the diameter 20 mm (D), giving an effective length to diameter ratio of 25 (L/D). The extruder was heated at four zones at the cylinder and the die. Throughout all the multiple extrusion cycles the screw rotation speed was kept at 50 rpm, yielding a throughput of around 1.2 kg per hour.

To investigate the effect of the reprocessing temperature on MFR retention of the reprocessed chair material, the following two different remelting temperature ranges were applied: (a) max. 260°C (temperatures of the four zones: 230/240/250/260°C) and (b) max. 280°C (250/260/270/280°C).

For selected compositions the influence of a twin-screw extruder was additionally checked. In particular, a single reprocessing cycle was performed for selected compositions using a Werner & Pfleiderer ZSK 25 twin-screw extruder. In this case, the screw rotation speed was kept at 100 rpm. This study was employed for examining the influence of the extruder type used, as it is known that a twin-screw extrusion cycle results in more severe polymer degradation.

Finally, as already mentioned, a repigmentation stage was applied to determine the effect of an additional pigment on the stability of repigmented chair material during reprocessing. For the purposes of this study, the reprocessing procedure was repeated at the two different temperatures selected, while applying five different stabilization compositions:

### Repigmentation

For repigmentation, a DPP Red® pigment, product of Ciba Specialty Chemicals Ltd., was used in the form of masterbatch and in a concentration level of 2% w/w.

### Homogenization procedure

A double-arm kneading mixer from Werner Company, with Sigma blades and mixing chamber of 1.50 L, was used for the dry blending and the homogenization of the additives with the chair material.

### Remelting and MFR retention

#### Reprocessing procedure

To investigate the optimum restabilization recipe for eliminating degradation effects during reprocessing a multiple extrusion procedure was applied including the following nine different routes. Nonrepigmented material was considered first.

1. **R1**: remelting of nonrestabilized material
2. **R2**: remelting of restabilized material using 0.2% w/w Recyclosorb 550®
3. **R3**: remelting of restabilized material using 0.4% w/w Recyclosorb 550®
4. **R4**: remelting of restabilized material using 0.2% w/w Recyclosorb 550® and 0.2% w/w Recyclostab 451®
5. **R5**: remelting of restabilized material using 0.4% w/w Recyclosorb 550® and 0.4% w/w Recyclostab 451®
1. **Rc1**: remelting of nonrestabilized material
2. **Rc2**: remelting of restabilized material using 0.2% w/w Recyclosorb 550®
3. **Rc3**: remelting of restabilized material using 0.4% w/w Recyclosorb 550®
4. **Rc4**: remelting of restabilized material using 0.2% w/w Recyclosorb 550® and 0.2% w/w Recyclostab 451®
5. **Rc5**: remelting of restabilized material using 0.4% w/w Recyclosorb 550® and 0.5% w/w Recycloblend 660®

It should be noted here that as the original chair material was white colored; the red pigment yielded in pink coloring.

#### MFR measurements

Melt Flow Rate (MFR) measurements were carried out for all different grades prepared according to the procedure A of the ASTM D1238-73 (or ISO 1133), using a Kayness Co. (Model 4004) capillary rheometer.

The temperature was fixed at 230°C, and the weight of the ram (load) was equal to 2160 g. Samples weights varied from 3–3.5 g. In all cases the average value is reported, while the coefficient of variation [c.v. = (standard deviation/average) × 100] was in all cases calculated lower than 2.5%.

### Mechanical performance

#### Specimens preparation

The aforementioned Werner & Pfeiderer ZSK 25 twin-screw extruder and an Arburg 221-75-350 injection-molding machine were used for specimens preparation. Passing before injection molding through the extruder ensures complete homogenization of the material.

Specimens were prepared only for the nonrepigmented material and for 11 different qualities:

1. **S0**: Original waste (PP chairs) material
2. **S1**: nonrestabilized material, reprocessed at 260°C
3. **S2**: restabilized material using 0.2% w/w Recyclosorb 550® and 0.2% w/w Recyclostab 451®, reprocessed at 260°C
4. **S3**: restabilized material using 0.4% w/w Recyclosorb 550® and 0.4% w/w Recyclostab 451®, reprocessed at 260°C
5. **S4**: restabilized material using 0.2% w/w Recyclosorb 550® and 0.2% w/w Recycloblend 660®, reprocessed at 260°C
6. **S5**: restabilized material using 0.2% w/w Recyclosorb 550® and 0.5% w/w Recycloblend 660®, reprocessed at 260°C
7. **S6**: restabilized material using 0.4% w/w Recyclosorb 550® and 0.5% w/w Recycloblend 660®, reprocessed at 260°C
8. **S7**: restabilized material using 0.4% w/w Recyclosorb 550® and 1% w/w Recycloblend 660®, reprocessed at 260°C
9. **S8**: nonrestabilized material, reprocessed at 280°C
10. **S9**: restabilized material using 0.2% w/w Recyclosorb 550® and 0.5% w/w Recycloblend 660®, reprocessed at 280°C

11. **S10**: restabilized material using 0.4% w/w Recyclosorb 550® and 1% w/w Recycloblend 660®, reprocessed at 280°C

#### Tensile impact tests

Tensile impact tests were carried out for all different grades according to the ISO 8256 or DIN 53 448 methods with a Zwick PSW 5101 tensile impact tester in standard laboratory atmosphere. The initial potential energy of the hammer was 25 J and the velocity at impact 3.4–4.1 m/s. Five samples of each composition were tested, and the average value and the coefficient of variation are reported.

#### Tensile tests

Tensile tests were carried out using an Instron 4466 tensile machine according to the D638-76 ASTM method in standard laboratory conditions, with a rate of extension equal to 50 mm/min. Five samples of each composition were tested, and the average value and the coefficient of variation are reported.

## RESULTS AND DISCUSSION

### MFR retention

Figures 1 and 2 illustrate the effect of five multiple single-screw extrusion cycles, on the Melt Flow Rate (MFR) of the PP-filled chair material at the remelting temperature of 260°C, for all different grades examined. As can be seen, a systematic increase in the MFR values is always recorded with the extent of reprocessing, i.e., with the number of the successive remelting cycles. It is worthwhile to mention that in some concentrations the MFR values increase very rapidly after the third remelting cycle, indicating complete consumption of the active antioxidants. This behavior is correlated to the aforementioned chain scission mechanism, which results in molecular weight degradation. This molecular weight degradation affects in the same way the melt viscosity leading to higher MFR values.<sup>10,11</sup>

However, it should be seen that the nonrestabilized grade presents the higher MFR values reflecting severe degradation in the molecular structure. In other words, the addition of the restabilization combinations employed seems to reduce or even eliminate the progress of the thermo-oxidation reactions during reprocessing, and in this way to ensure melt viscosity retention. It is also obvious that the restabilization type as well as the restabilization levels employed comprise crucial parameters.

The same view it can be also observed in Figures 3 and 4, where the effect of reprocessing on MFR values at remelting temperature of 280°C is plotted. As ex-

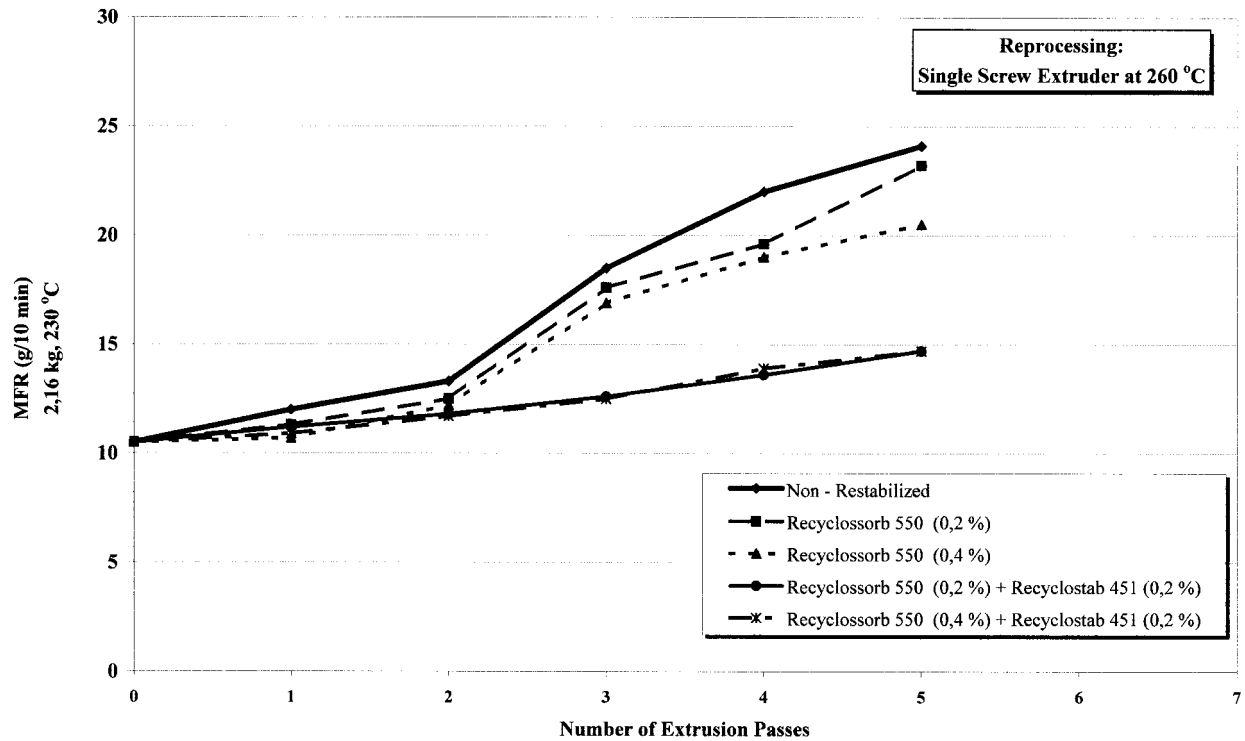


Figure 1 PP-filled garden chairs, nonpigmented material: effect of multiple extrusion on MFR at 260°C -I.

pected, here the MFR changes seem even more severe due to the higher reprocessing temperature.

Turning now to the restabilization combinations employed in this study, it should be noticed that only

the addition of the restabilization system Recyclosorb 550® alone is not enough to effectively eliminate the degradation of the recycled material, although this system had proven to be very effective in other cas-

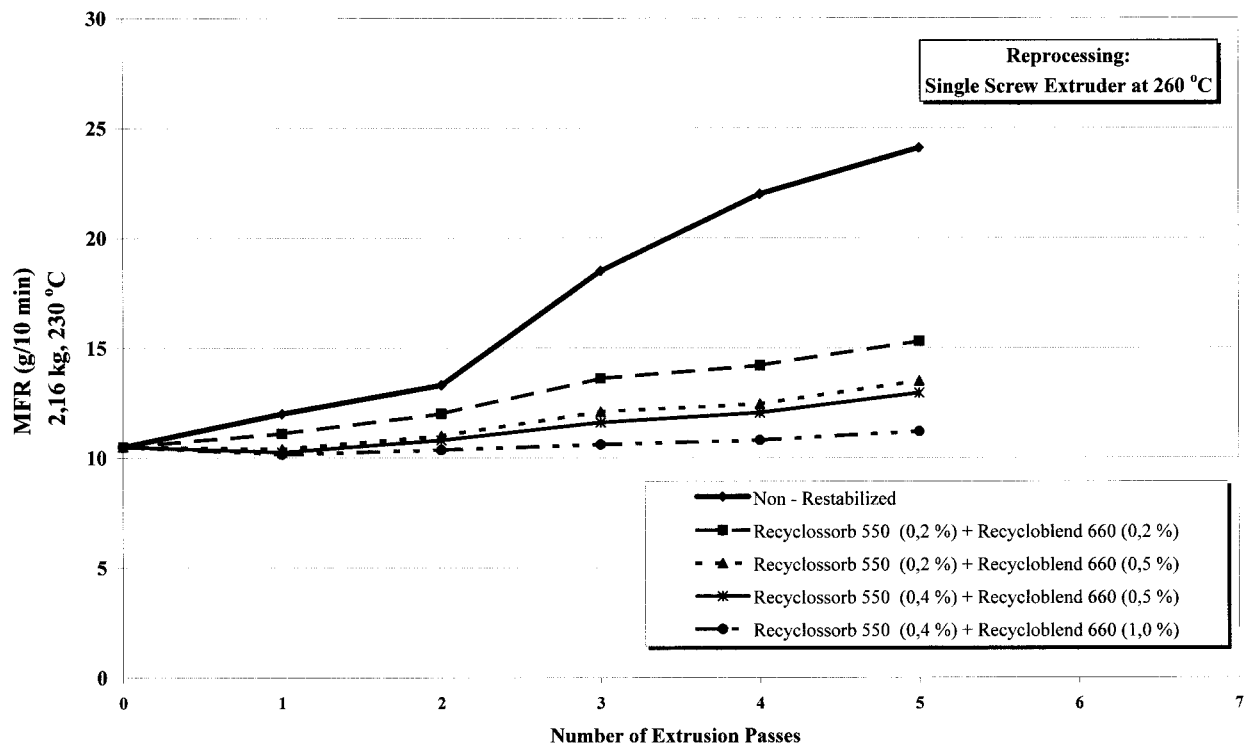


Figure 2 PP-filled garden chairs, nonpigmented material: effect of multiple extrusion on MFR at 260°C-II.

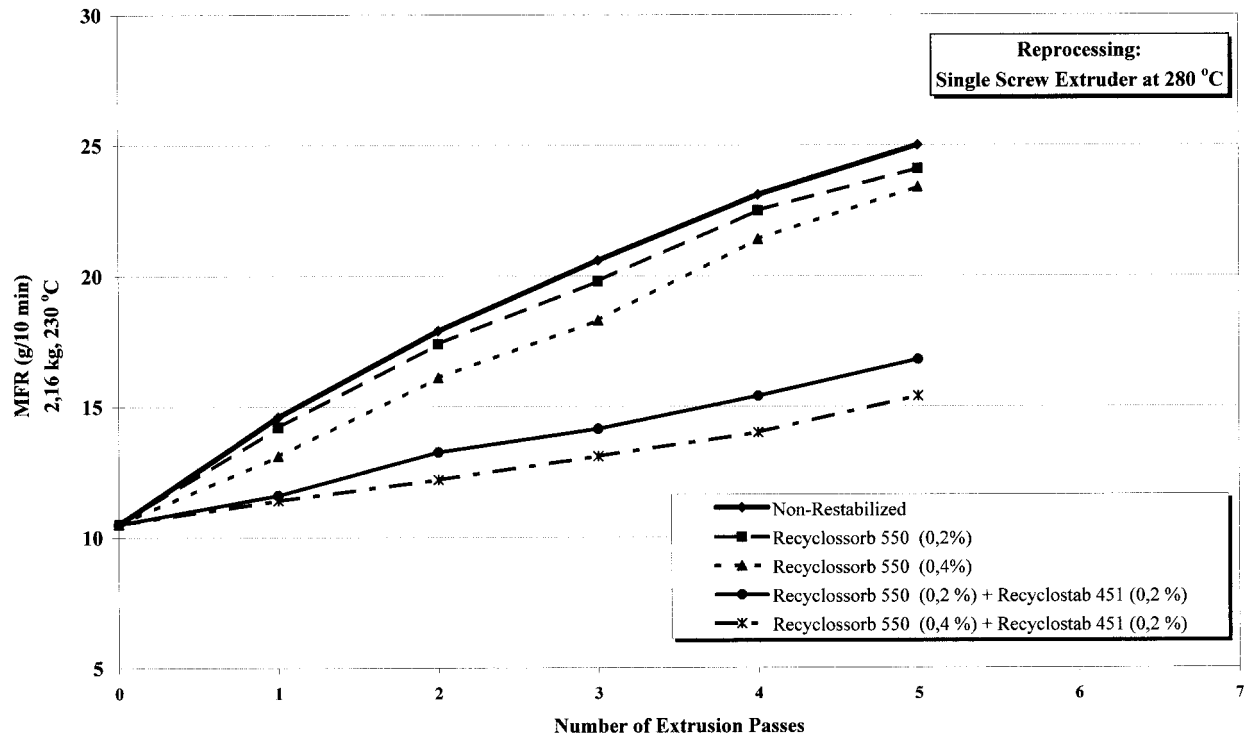


Figure 3 PP-filled garden chairs, nonrepigmented material: effect of multiple extrusion on MFR at 280°C-I.

es.<sup>13,14,16</sup> This should not be surprising, because of the nature of the polymeric material examined. As already mentioned, the presence of the inorganic filler (CaCO<sub>3</sub>) in the polymer matrix should have a negative

effect on the antioxidant action of the Recyclosorb 550®. On the other hand, the combination of the Recyclosorb 550®, with the Recyclostab 451®, a stabilization system specifically developed to offer process-

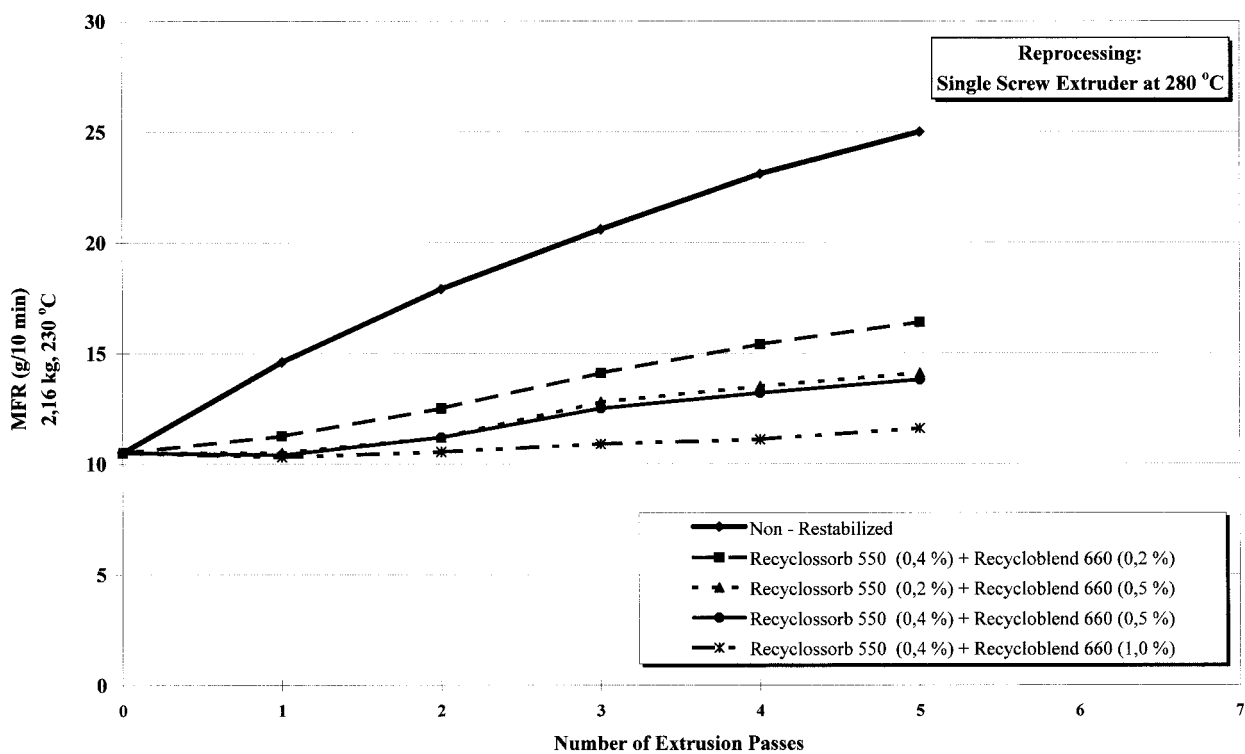
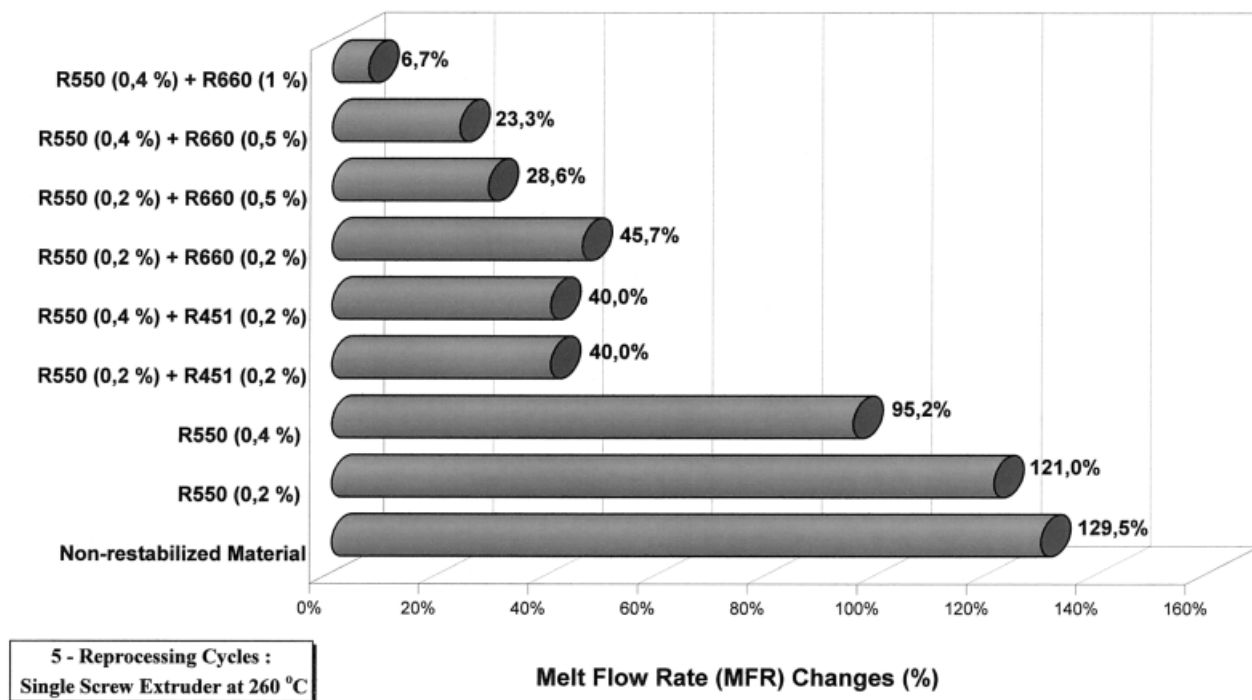


Figure 4 PP-filled garden chairs, nonrepigmented material: effect of multiple extrusion on MFR at 280°C-II.



**Figure 5** PP-filled garden chairs, nonrepigmented material: MFR changes (%) after five successive reprocessing cycles at 260°C in a single-screw extruder.

ing stability protection for recycled polypropylene, improves the processing stability of the recycled material, but still in limited levels (Figs. 1 and 3). On the contrary, the addition of the Recycloblend 660®, which acts as a deactivator for foreign matter, such as the inorganic fillers, effectively eliminates the negative action, permitting to the antioxidant content of the Recyclossorb 550® to act efficiently in blocking the oxidation reactions (Figs. 2 and 4). Note that the addition of 1% w/w of the deactivator can almost exclude any MFR changes even after five remelting cycles in the higher reprocessing temperature of 280 °C.

The aforementioned observations become more profound in Figures 5 and 6, where the percent changes of the MFR values after five successive remelting cycles are plotted for all different grades studied. In particular, Figure 5 presents the %MFR changes at the reprocessing temperature of 260°C, while Figure 6 presents the same data at the reprocessing temperature of 280°C. In both cases it is clear that the use of the filler deactivator (Recycloblend 660®) is essential for maintaining the rheological properties of the recycled PP-filled chair material during reprocessing.

Figures 7 and 8 present the effect of a single reprocessing cycle on the MFR of the PP-filled chair material, using the twin-screw extruder. As can be seen, the reprocessing with the twin-screw extruder affects the rheological stability of the different grades examined in a quite similar way with this described in the case of

the single-screw extruder. The nonrestabilized grade always presents the higher MFR values in both operation temperatures. In addition, all restabilized grades present a remarkable retention of the Melt Flow Rate (MFR), but again the restabilization type and the restabilization level employed plays a critical role. For example, the addition of 1% w/w of Recycloblend 660®, offers an excellent stability on the recycled material, even at the higher reprocessing temperature of 280°C. Finally, the results are in accordance with the well-known fact that twin-screw extrusion creates more degradation than single-screw extrusion. Note that the changes in the MFR values reported after five reprocessing cycles with the single-screw extruder (Figs. 5 and 6) are often in the same range with the MFR changes after a single pass in the twin-screw extruder (Figs. 7 and 8).

The effect of multiple extrusion on MFR of repigmented material using the single-screw extruder, is presented in Figure 9 for the five different repigmented grades studied. Data at 260°C are presented here. The data reveals that the repigmented material presents a rheological behavior similar to the nonrepigmented material for both restabilized and nonrestabilized grades. In other words, because of the low concentration in which it was used, the pigment has a negligible influence on the melt viscosity of the polymeric material, in accordance with literature findings.<sup>18</sup> It is important to mention that the data, at 280°C, indicate also the same trend.

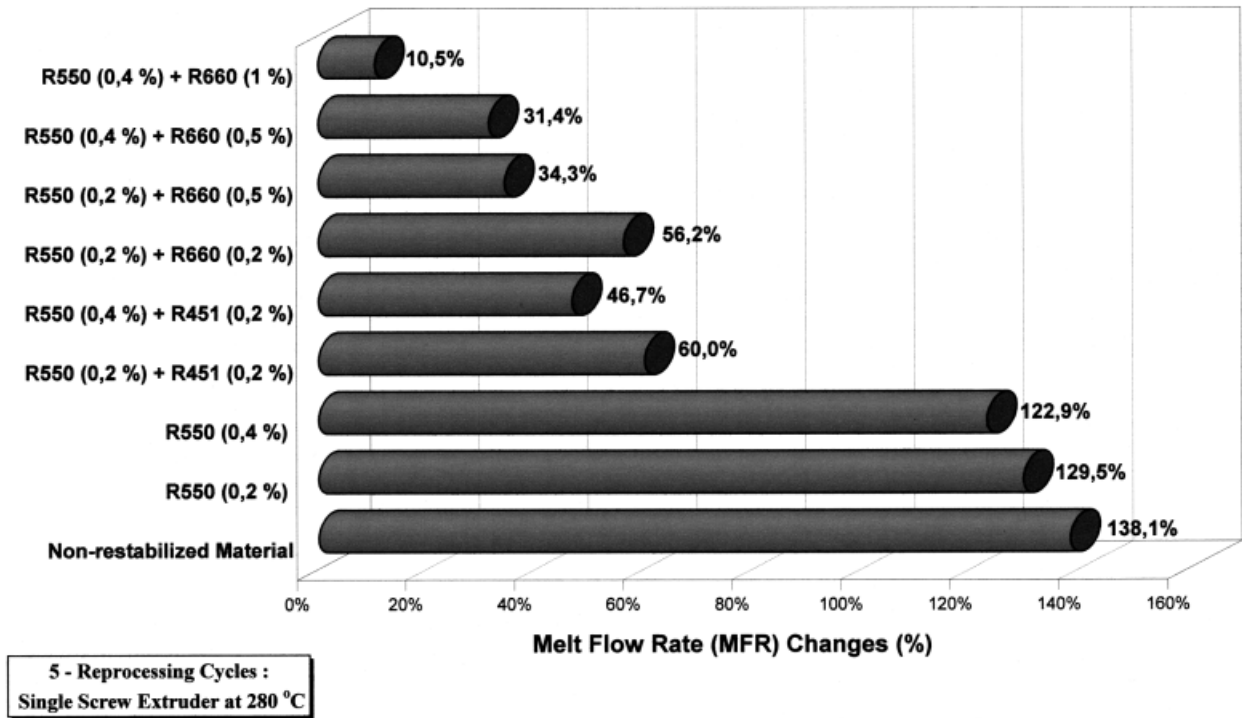


Figure 6 PP-filled garden chairs, nonrepigmented material: MFR changes (%) after five successive reprocessing cycles at 280°C in single-screw extruder.

**Mechanical performance**

Figures 10 and 11 demonstrate the effect of reprocessing on the tensile strength of restabilized and nonrestabilized specimens, prepared at 260 and 280°C, re-

spectively. As can be seen, in both cases the nonrestabilized material presents the lower values, reflecting extended degradation in the polymeric chains due to thermo-oxidation, which leads to deterioration of the

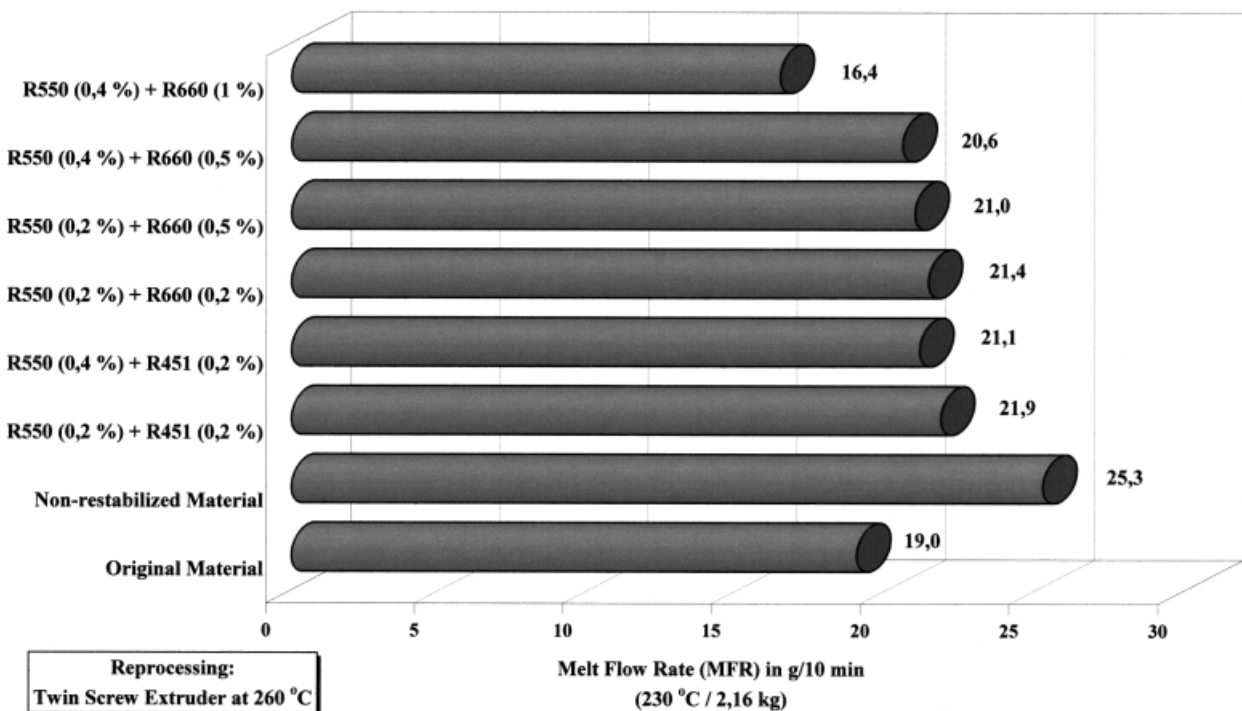


Figure 7 PP-filled garden chairs, nonrepigmented material: effect of reprocessing on MFR using a twin-screw extruder at 260°C.



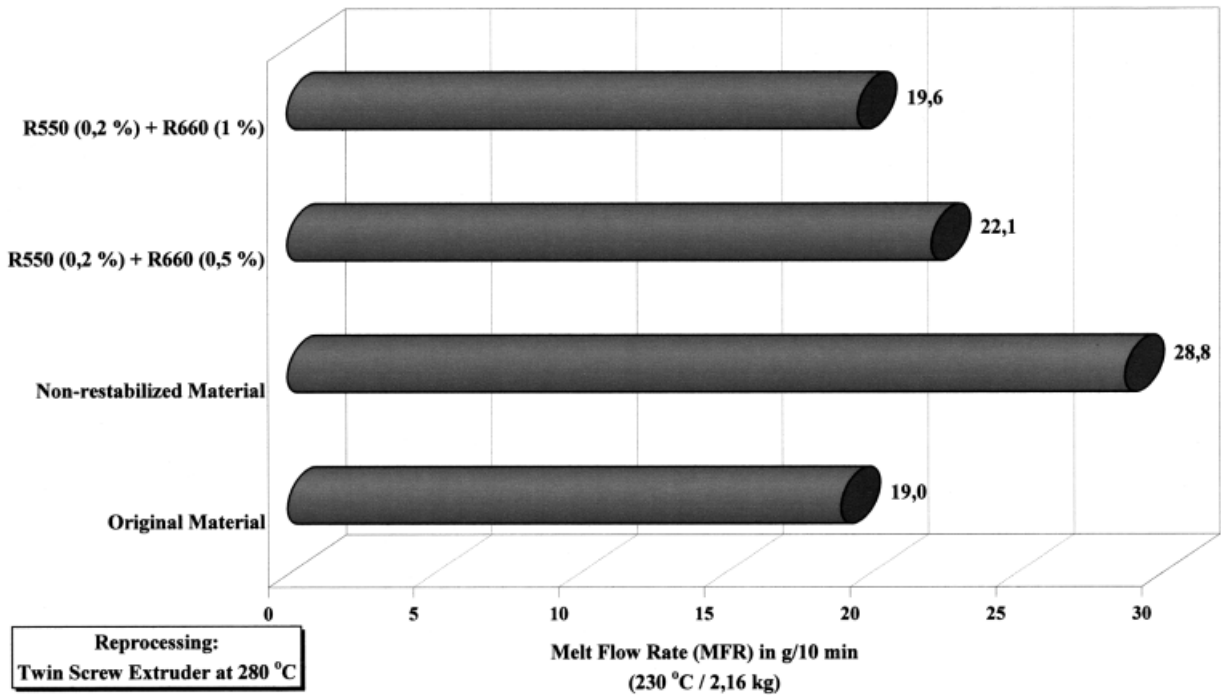


Figure 8 PP-filled garden chairs, nonrepigmented material: effect of reprocessing on MFR using a twin-screw extruder at 280°C.

tensile strength. For the nonrestabilized grades, either at 260 or 280°C, the tensile strength decline from the initial value of the “original material” was calculated in the level of about 12%. On the other hand, the restabilization employed improves significantly the

retention of the tensile strength values, while the recipe seems again to be a crucial factor. In fact, the results show that combining 1% w/w from the filler deactivator (Recycloblend 660®) with 0.4% w/w of Recyclosorb 550® yields in a very satisfactory re-

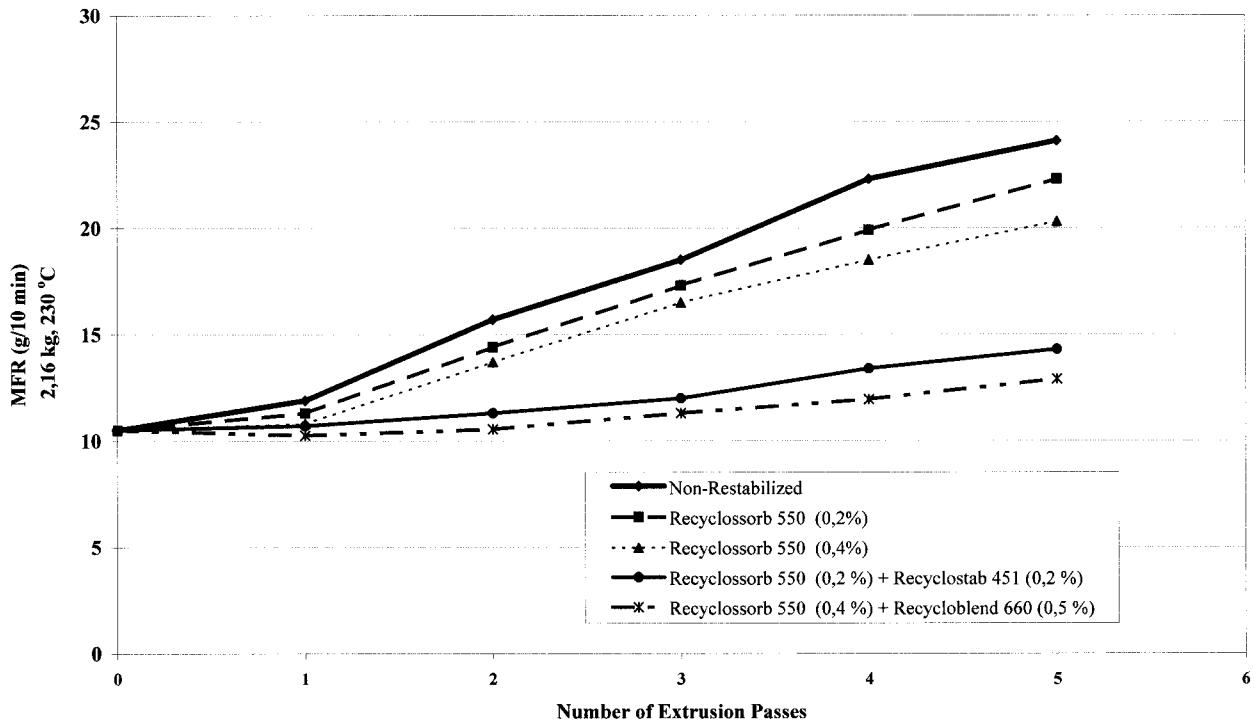


Figure 9 HDPE crates, repigmented material: effect of multiple extrusion on MFR at 260°C.

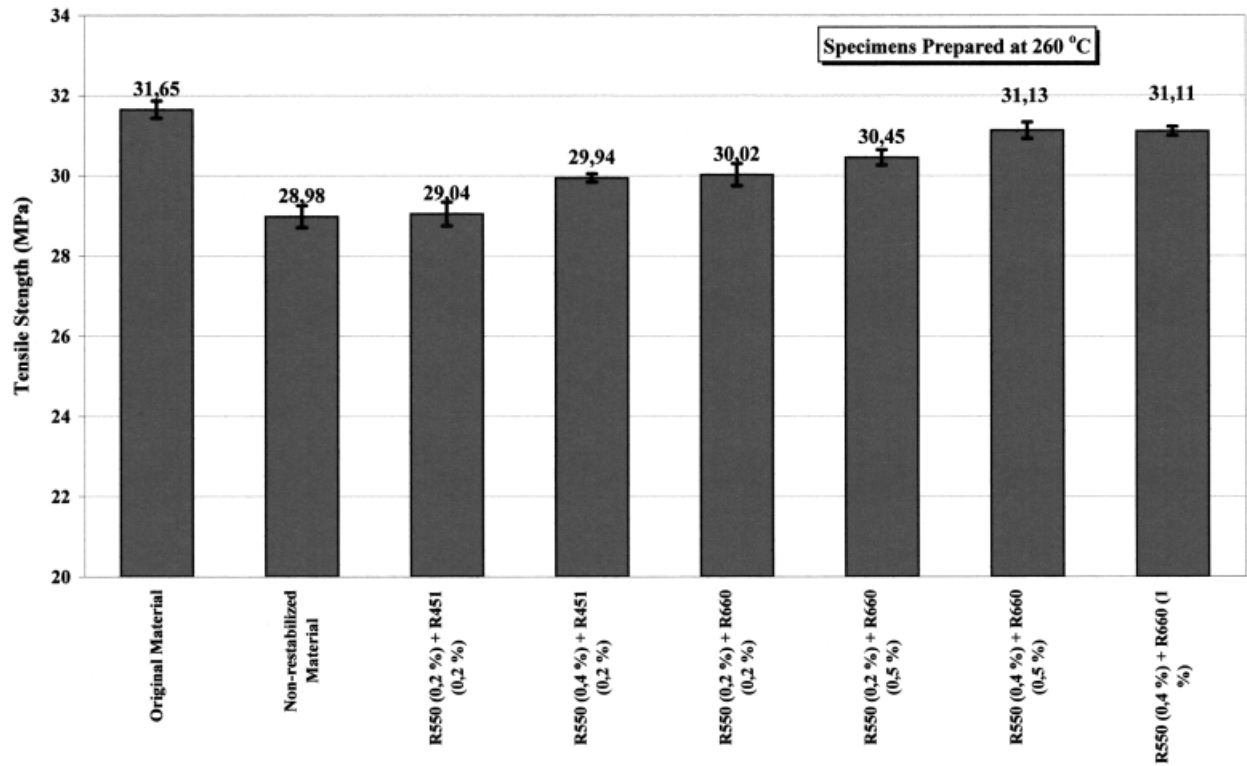


Figure 10 Tensile strength of recycled PP-filled garden chairs, reprocessed at 260°C.

tention of the tensile strength. Note that this is the case even at the higher reprocessing temperature of 280°C.

The elongation at break for all qualities reprocessed at 260 and 280°C are presented in Figures 12 and 13, respectively. As can be seen, an elongation improve-

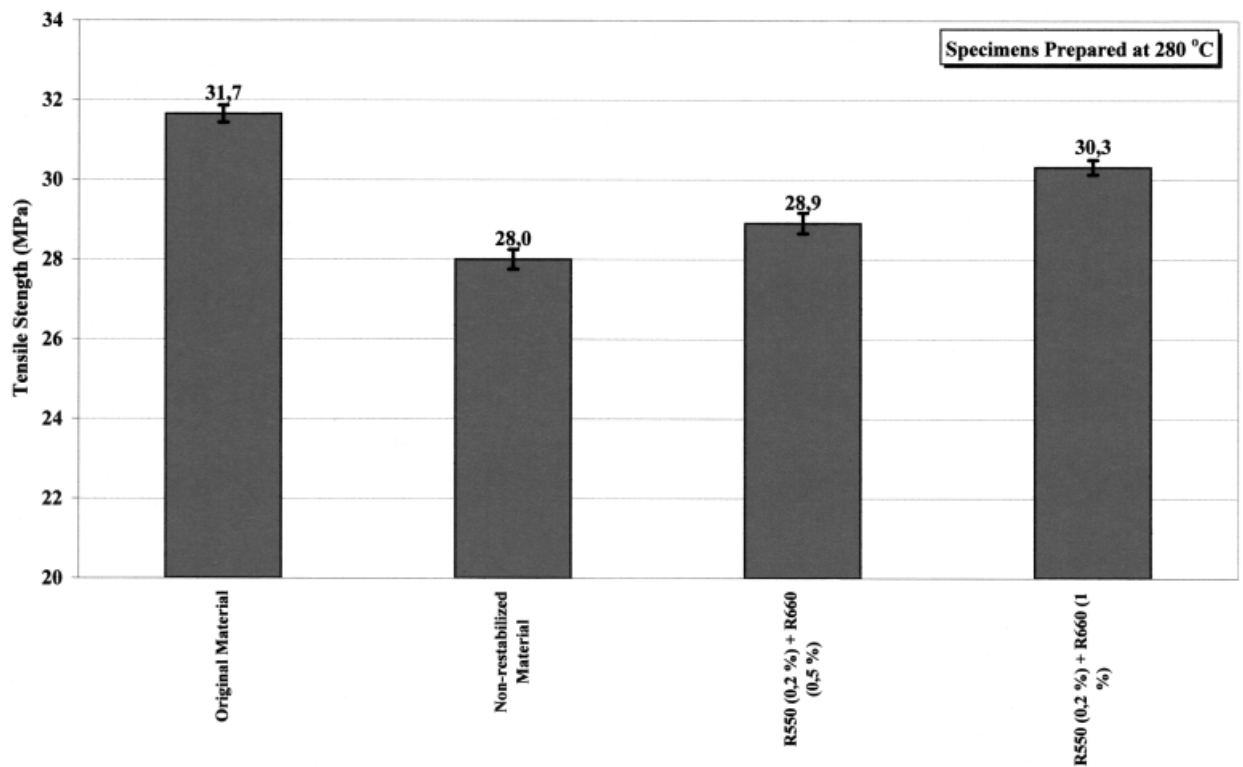


Figure 11 Tensile strength of recycled PP-filled garden chairs, reprocessed at 280°C.

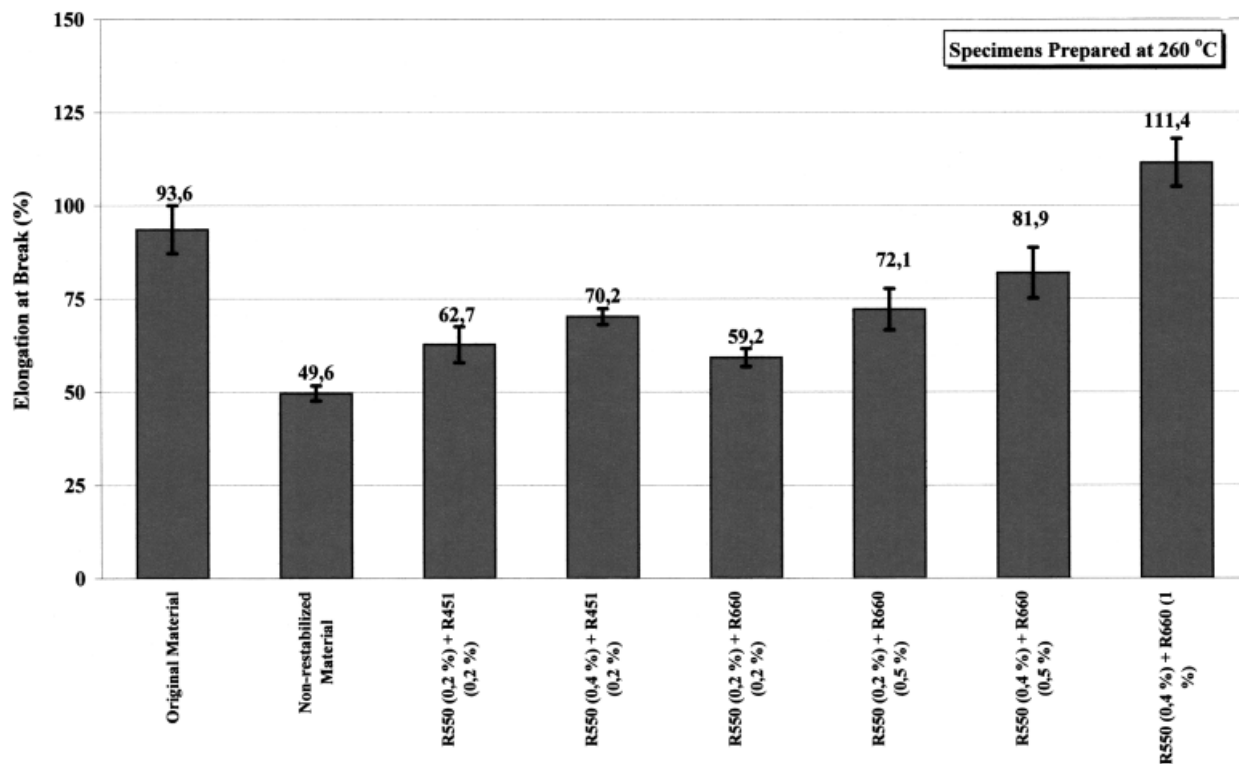


Figure 12 Elongation at break of recycled PP-filled garden chairs, reprocessed at 260°C.

ment is clearly observed for all restabilized grades. It is obvious that any thermo-oxidative degradation induced in the polymer structure during reprocessing

results in poor elongation in a tensile mode experiment. However, the addition of the restabilization agents prolongs the processing stability of the PP-

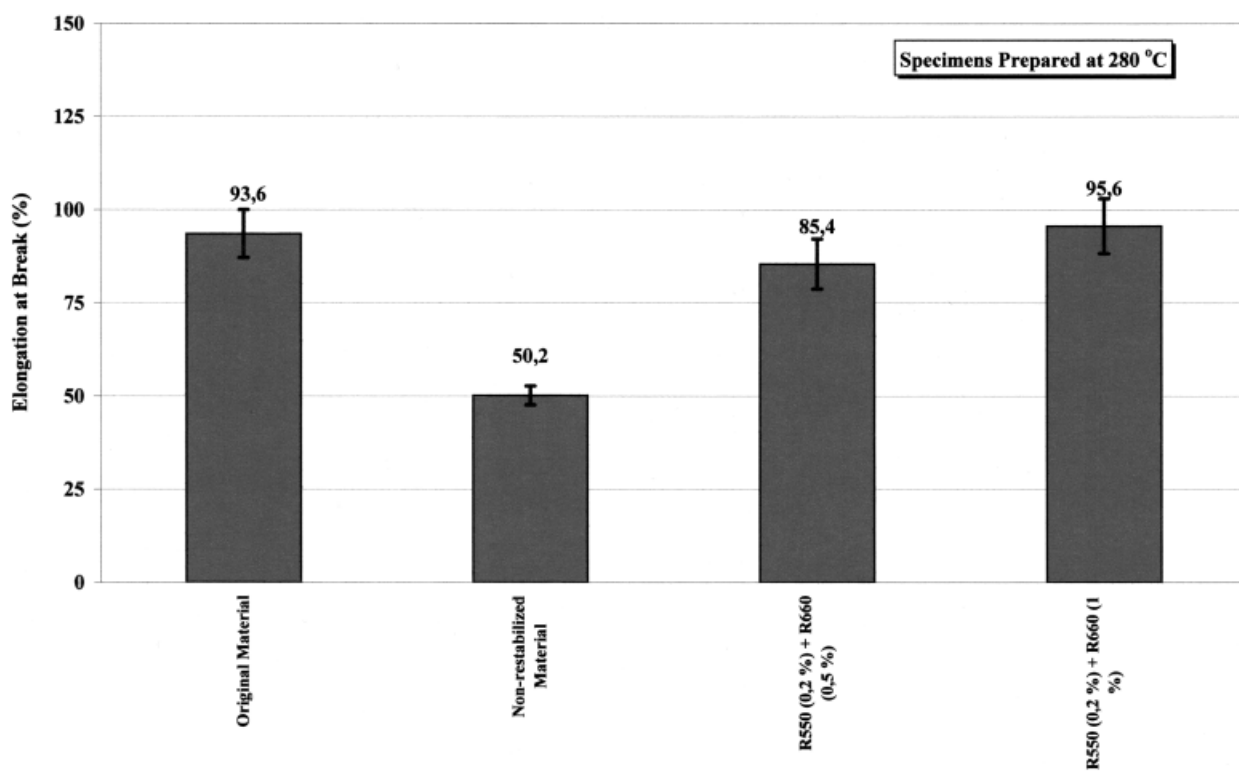


Figure 13 Elongation at break of recycled PP-filled garden chairs, reprocessed at 280°C.

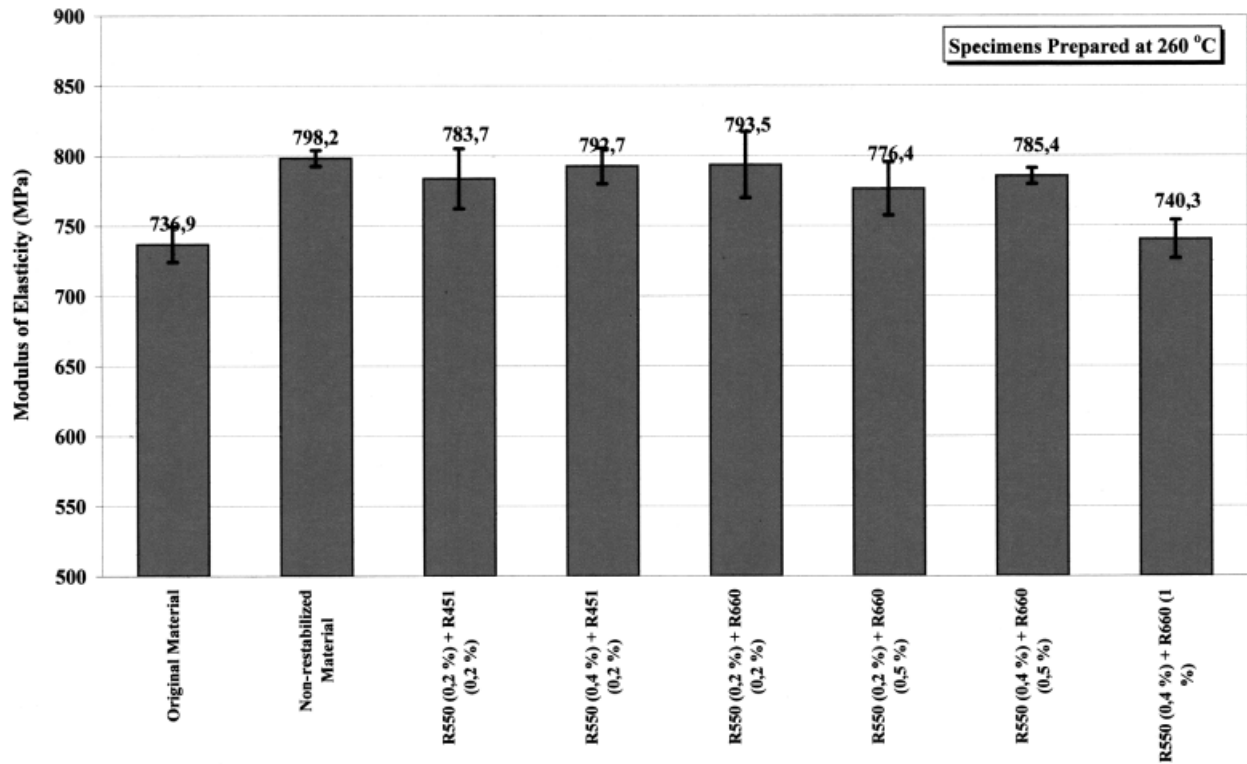


Figure 14 Modulus of elasticity of recycled PP-filled garden chairs, reprocessed at 260°C.

filled chair material, yielding in distinct improvement of the elongation. Again, the synergism of the filler deactivator with a sufficient content of antioxidants

presents the most promising results. In harmony with literature findings it should be pointed out here that the elongation at break is strongly affected from the

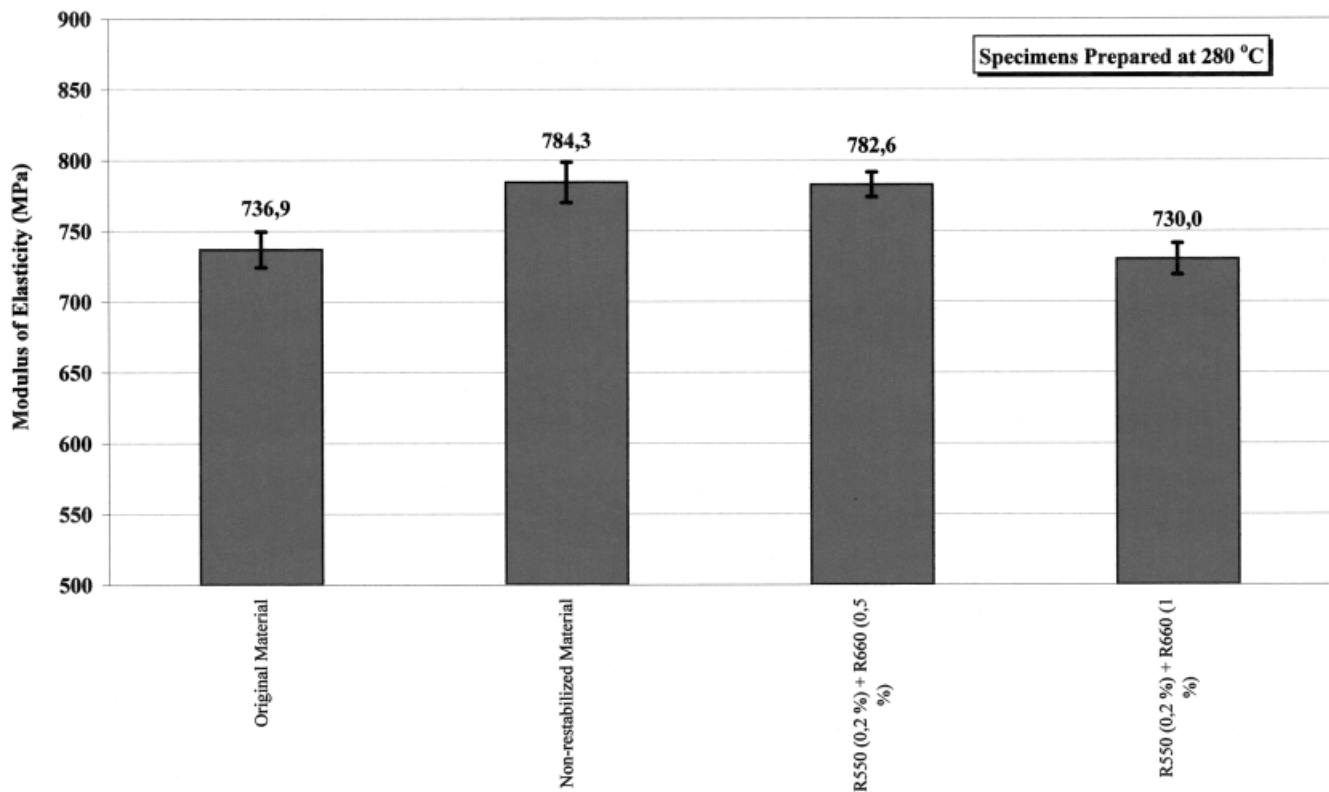


Figure 15 Modulus of elasticity of recycled PP-filled garden chairs, reprocessed at 260°C.

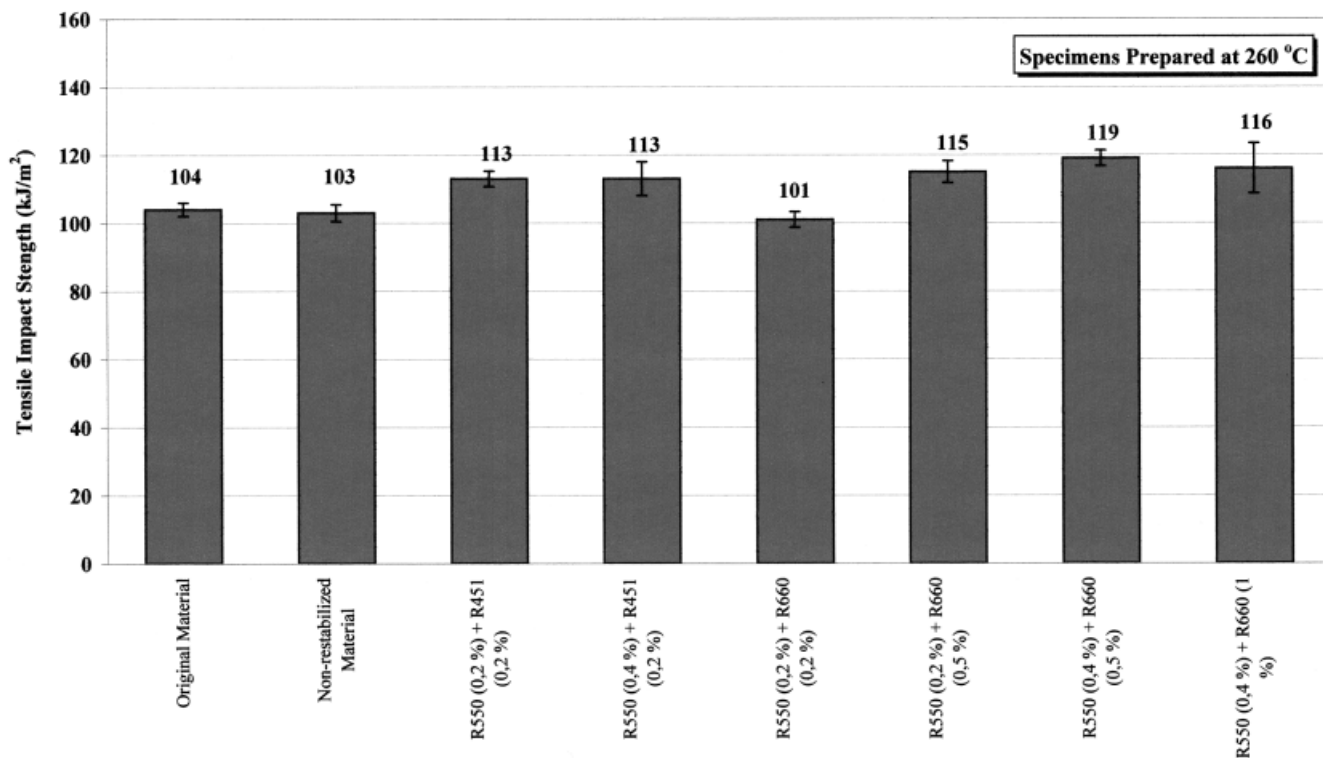


Figure 16 Tensile impact strength of recycled PP-filled garden chairs, reprocessed at 260°C.

extent of oxidative degradation in the material structure. Especially in the case of polypropylene matrices, oxidation reactions during reprocessing dramatically reduce the polymeric chains length, in the same way influencing the material extensibility.<sup>11</sup>

Figures 14 and 15 present the modulus of elasticity for all different specimens prepared. The effect of reprocessing results in a slight increase of the tensile modulus values for both restabilized and nonrestabilized grades. This trend is in line with the aforementioned decrease of the elongation values. In particular, the data indicate that during reprocessing the original chair material gradually loses its ductility and becomes brittle. On the contrary, the addition of the suitable composition of the restabilization systems can ensure the retention of the original elastic behavior of the chair material.

Finally, again for specimens reprocessed at 260 and 280°C, Figures 16 and 17 represent the effect of reprocessing on the tensile impact strength of the PP-filled chair material. As can be seen, in both cases, there is not a remarkable deviation in the values encountered from the different restabilization recipes. It should also be pointed out that some differences recorded stand within the standard deviation limits. These results reveal that in contrary with the aforementioned view of the tensile properties the oxidative degradation induced during reprocessing does not seem to dramatically affect the tensile impact strength of the recycled material. The latter could possibly be explained by the fact that the tensile impact strength

mainly depends on the specimen's surface and thus is very sensitive on the surface condition. In line with this approach, because the surface of all specimens prepared after reprocessing was in perfect condition, no remarkable differences in the tensile impact values of the restabilized or nonrestabilized grades were detected. On the contrary, tensile properties are much more sensitive to the material microstructure, and thus are strongly influenced by oxidation changes occurred in the polymer matrix.

## CONCLUSIONS

The remelting–restabilization technique is applied for recycling of postused, white pigmented garden chairs based on filled PP. During the reprocessing procedure, the unprotected (nonrestabilized) chair material suffers from oxidative degradation, due to well-known chain scission phenomena along the polymer structure, leading to molecular weight deterioration and consequently to melt flow rate increase resulting finally in insufficient mechanical properties. On the other hand, the addition of restabilization systems especially developed for the protection of polymer matrices against the oxidation effect, can eliminate, or at least reduce the polymer chain degradation of the recycled material, considerably improving its processing stability during repeated remelting cycles. However, the results indicate that, within our experimental conditions, the restabilization recipe is of crucial importance for yielding sufficient stabilization, espe-

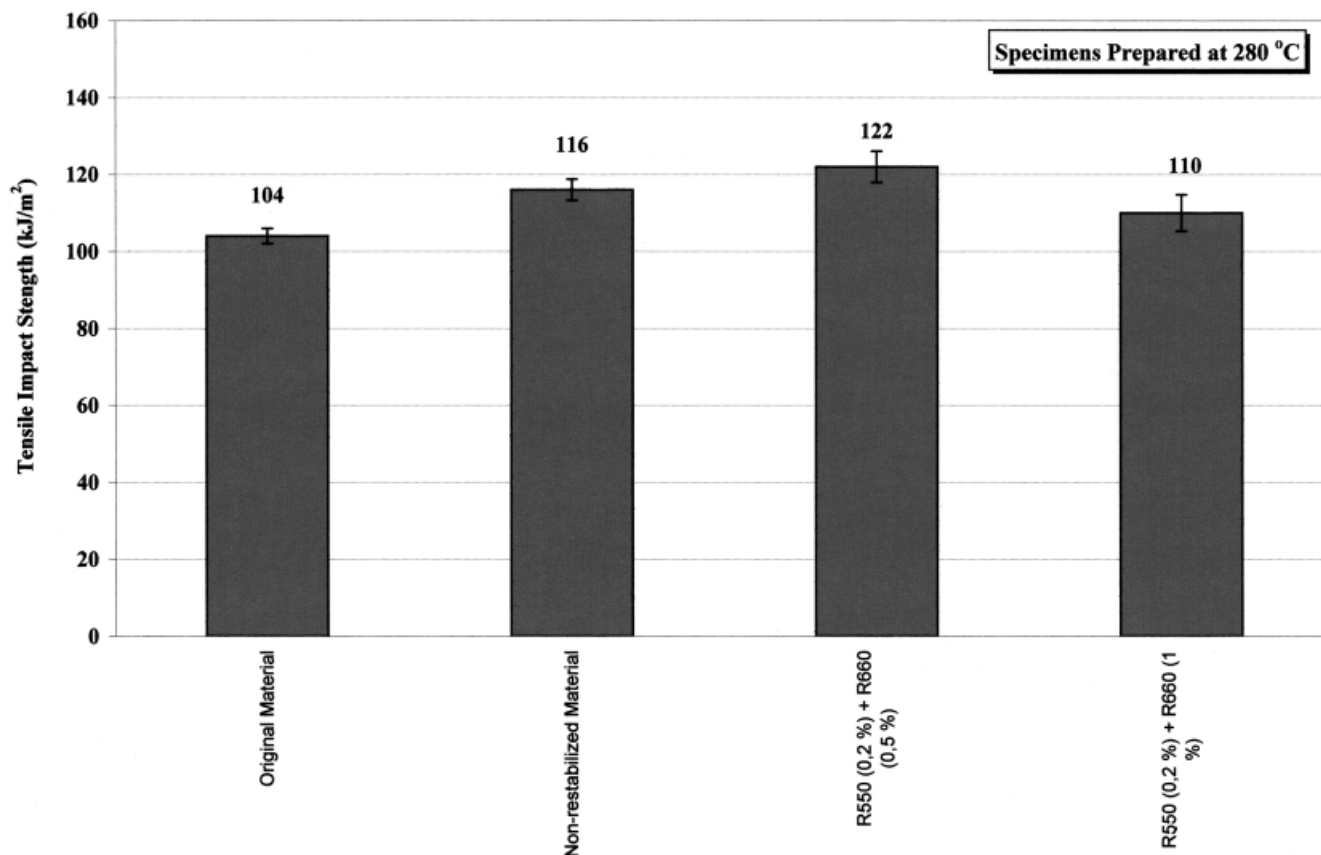


Figure 17 Tensile impact strength of recycled PP-filled garden chairs, reprocessed at 280°C.

cially at a high remelting temperature. In all cases studied the addition of the filler deactivator proved to be essential for overcoming the negative effect of the inorganic filler.

Tensile tests proved that the addition of restabilization systems is mandatory for maintaining the mechanical properties such as tensile strength, modulus, and elongation. It turned out that the elongation is the property most influenced by degradation caused by insufficient protection of the polymer. Again, the best results are encountered with the synergetic action of the filler deactivator and antioxidants in the appropriate quantities.

The results presented so far on processing will be completed through heat aging and artificial weathering experiments.

The authors thank Mr. P. Stathis (Additive Hellas Ltd.) for generously supplying the chair material.

## References

- Ehring, J. R. *Plastics Recycling Products and Processes*; Carl Hanser: New York, 1992.
- Pfaendner, R.; Herbst, H.; Hoffmann, K.; Sitek, F. *Angew Makromol Chem* 1995, 232, 193.
- Pfaendner, R.; Herbst, H.; Hoffmann, K. *Eng Plastics* 1996, 9, 249.
- Pfaendner, R.; Herbst, H.; Hoffmann, K. *Macromol Symp* 1998, 135, 97.
- Pospisil, J.; Sitek, F.; Pfaendner, R. *Polym Degrad Stabil* 1995, 48, 351.
- Herbst, H.; Pfaendner, R. *Multifunctional Additives Opens New Perspectives in the Field of Plastics Recycling, R'99; Recovery, Recycling, Re-Integration, 4th International Congress Proceedings, Geneva, Switzerland, 2-5 February, 1999*; p III-177.
- Hinsken, H.; Moss, S.; Pauquet, J. R.; Zweifel, H. *Polym Degrad Stabil* 1991, 34, 279.
- Drake, W. O.; Pauquet, J. R.; Todesco, R. V.; Zweifel, H. *Angew Makromol Chem* 1990, 176/177, 215.
- Moss, S.; Zweifel, H. *Polym Degrad Stabil* 1989, 25, 217.
- Scott, G. *The Role of Stabilising Additives in Polymer Recycling; Davos Recycle'93 International Forum and Exposition, Davos, Switzerland, March 22-26, 1993*.
- Zweifel, H. In *Stabilization of Polymeric Materials*; Springer-Verlag: Berlin, 1998; p 1.
- Schwarzenbach, K. In *Plastics Additives Handbook*; Gächter, R.; Müller, H., Eds.; Hanser Publishers: New York, 1984, p. 3, 2nd ed.
- Kartalis, N.; Papaspyrides, C. D.; Pfaendner, R.; Hoffmann, K.; Herbst, H. *J Appl Polym Sci* 1999, 73, 1775.
- Kartalis, C. N.; Papaspyrides, C. D.; Pfaendner, R.; Hoffmann, K.; Herbst, H. *J Appl Polym Sci* 2000, 77, 1118.
- Kartalis, C. N.; Papaspyrides, C. D.; Pfaendner, R. *Polym Degrad Stabibil* 2000, 70, 189.
- Kartalis, C. N.; Papaspyrides, C. D.; Pfaendner, R.; Hoffmann, K.; Herbst, H. *Polym Eng Sci*, accepted.
- Allen, N.; Edge, M.; Corrales, T.; Catalina, F. *Polym Degrad Stabil* 1998, 61, 139.
- Gächter, R.; Müller, H. *Plastics Additives*; Hanser Publishers: New York, 1995; p 480.