Closed-Loop Recycling of Postused PP-Filled Garden Chairs Using the Restabilization Technique. Part 2: Material Performance during Accelerated Heat Aging

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Received 18 March 2002; accepted 26 April 2002

ABSTRACT: The long-term thermal stability of postused $CaCO_3$-filled Polypropylene was evaluated through accelerated heat aging tests for about 2000 h. The material from old garden chairs was recycled by applying the remelting-restabilization technique while using different stabilization systems in selected concentrations. To study the effect of heat aging on the material properties, crystallinity content, tensile strength, and tensile impact strength together with time to embrittlement were monitored. The results illustrate that the restabilization recipe is of crucial importance for improving the long-term thermal stability of the postused chair material, ensuring its reuse in the original application. Best long-term performance is achieved by combining a filler deactivator with appropriate heat and light stabilizer systems.

J Appl Polym Sci 88: 3033–3044, 2003

Key words: plastics; recycling; ageing

INTRODUCTION

Reusing old plastics in high-value applications means that the recyclate has to meet the needs and property requirements of the particular virgin resin to be replaced. However, new structural moieties formed during the first life cycle of the polymer, resulting in deterioration of the molecular weight and in mechanical properties loss, differentiate postused grade from the corresponding virgin material.[1–3]

End products in the course of their useful lifetime are subjected to widely differing thermal and environmental (e.g., UV-light) stresses and in this way undergo oxidation. The oxidation mechanism is initiated by the formation of alkyl radicals (R·) under the influence of heat, impurities, and peroxide radicals (ROO·) formed during the processing step. These alkyl radicals react with molecular oxygen forming oxidation products, such as hydroperoxides (ROOH), and new alkyl radicals, which restart the oxidation cycle. In this way, during this cycle, irreversible structural changes take place at both molecular and morphological levels resulting in molecular weight degradation and mechanical performance loss.[4–6]

In partially crystalline polymers with originally ductile characteristics, such as polypropylene (PP), loss of mechanical properties in the course of heat aging is the result of molecular weight degradation caused by C—C chain scission mechanism, leading to molecular weight reduction and transition from ductile to brittle behavior. Additionally, this mechanical properties failure is also associated with microcrack formation on the product surface because of diffusion-controlled aging. Crack formation starts from oxidized, brittle surface, and subsequent propagates into the ductile material under mechanical stress.[6–9]

The described negative effects of heat aging can be avoided or limited by means of stabilization. However, in the case of recyclates, the original stabilizers are consumed during the primary conversion process and first service life and, therefore, the active stabilizer content becomes usually insufficient to protect the polymer during its second life cycle.[2,3,5,7]

By adding new amounts of suitable stabilizers for processing and long-term protection, the "old material" can be often reused in its original application. In other words, restabilization, probably the most effective approach to upgrade recyclates, can improve the processing and long-term thermal stability of the recycled product generating in this way its required longevity and value.[1–3,10–14] As a rule, however, the restabilization recipe becomes very crucial for achieving better results. This recipe is highly dependent on the polymeric matrix type, the polymer morphology, and structure as well as on the type of the targeted application.

In this study a material stream of postused garden chairs made from filled PP is investigated. Here, the

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Journal of Applied Polymer Science, Vol. 88, 3033–3044 (2003)

predamage combined with the influence of the inorganic filler reduces dramatically the long-term thermal stability of the recycled product. For instance, it is known that polar groups on the filler surface adsorb antioxidants by interfering with hydroxy, ester, or amine groups of the antioxidants, thus reducing their protective function.[11,15,16] In addition to adsorption processes, metal ion impurities incorporated in the natural filler material may play a role. Therefore, a significant impact of fillers on the long-term thermal stability is well known. Filler deactivators or filler modifiers reduce the adsorption of the stabilizers and improve again the stability.[11,17–20]

To be on the safe side, as far as the second-life application is considered, the long-term performance of the recycled material should be carefully studied after restabilization. Long-term thermal stability can be determined by means of oven aging tests at relatively elevated temperatures. In this case, the criteria considered include visual inspection and assessment, as well as mechanical tests and determination of time to embrittlement.[2,3,14,21–23] This oven aging technique is more realistic in resembling conditions encountered by the plastics in use than other thermal analysis techniques, such as DSC or DTA.[22,23]

Recently, Ciba Specialty Chemicals Ltd. examined the possibility of upgrading postused stadium seats made from PP filled with 30% talcum, through restabilization. The results proved that only the addition of typical stabilizing agents could not improve effectively the thermal stability of the recyclate due to the inorganic filler negative effect. It is the addition of a typical filler deactivator that proved to be essential for improving the long-term stability of the recycled product.[16] In other studies from this company the same filler deactivator proved to be very effective, by eliminating the negative effect of residual inks and paints in the mechanical performance of car bumpers made of PP/EPDM.[15,16] However, the present series of articles is, to our knowledge, the first systematic investigation of the performance of filled recyclates.

In the first part of our study, carried out jointly at NTUA and Ciba Spezialitätenchemie Lampertheim GmbH, different stabilization systems in selected concentrations were employed to investigate the optimum restabilization recipe for eliminating degradation effects during reprocessing of the postused, PP-filled material from garden chairs.[20] In this article, the same stabilization recipes are followed and the long-term thermal stability of the same chair material is studied. Specimens of the recycled chair material were stored at 135°C for about 2000 h in a circulating air oven, and during this accelerated test the crystallinity content was first monitored. Additionally, time to embrittlement was determined, for all different grades prepared, while tensile and tensile impact tests were carried out for following the mechanical performance of the recycled material during heat aging. Furthermore, for selected compositions surface microphotographs were taken to investigate any effects on the surface of the final recycled product.

EXPERIMENTAL

Starting material

An amount of 100 kg of postused, white pigmented, garden chairs manufactured from filled PP was randomly collected from a local landfill in Greece. The age of the postused chairs collected was estimated between 3 to 5 years. The chairs were carefully washed, dried, and then they were shredded and stored. Analysis of the homogenized chair material shows that it contained 15% $CaCO_3$ in average, while the basic pigment was TiO2.

Analysis of residual stabilizer content, carried out using HPLC technique, resulted only in a small quantity of active stabilizers in the range of: (a) approximately 350 ppm phenolic type primary antioxidants, (b) no active phosphite based secondary antioxidants, and (c) no active epoxide as filler deactivator.

Restabilization systems

Three different stabilizer systems from Ciba Specialty Chemicals Ltd. were employed in selected concentrations to develop the optimum restabilization recipe for eliminating degradation effects during accelerated heat aging. These restabilization systems were chosen with the aim to reuse the material again in the form of garden chairs.

Recyclostab 451®

Stabilization system based on different types of antioxidants and costabilizers specifically developed to offer long-term thermal protection for recycled plastics, especially for polypropylene and polyolefin blends.

Recyclossorb 550®

Stabilization system specifically developed for light stabilization of recycled plastics, but also it provides basic heat stability to polyolefin recyclates. It is a mixture of antioxidants, costabilizers, and light stabilizers.

Recycloblend 660®

Stabilization system specifically developed for polyolefins against the negative influence of impurities, such as paint or ink residues during processing and application. Furthermore, it acts as a deactivator for compounds such as carbon black, fillers, etc. It con-

TABLE I
PP-Filled Chair Material Reprocessed at 260°C: Effect of Heat Aging on Thermal Behavior during Melting

S0.	Original waste-chair material			
Duration of heat aging	0 h	500 h	1000 h	2000 h
Melting point temperature (°C)	164.3	157.2	158.3	157.2
Melting range (°C)	24.2	21.8	24.5	22.2
S1.	Nonrestabilized material, reprocessed at 260°C			
Duration of heat aging	0 h	500 h	1000 h	2000 h
Melting point temperature (°C)	162.4	155.1	155.2	156.7
Melting range (°C)	24.4	19.6	23.2	25.5
S2.	Restabilized material using 0.2 % w/w Recyclossorb 550 + 0.2 % w/w Recyclosstab 451, reprocessed at 260°C			
Duration of heat aging	0 h	500 h	1000 h	2000 h
Melting point temperature (°C)	164.6	162.8	162.1	161.9
Melting range (°C)	29.0	29.3	30.6	29.8
S3.	Restabilized material using 0.4 % w/w Recyclossorb 550 + 0.2 % w/w Recyclosstab 451, reprocessed at 260°C			
Duration of heat aging	0 h	500 h	1000 h	2000 h
Melting point temperature (°C)	164.0	164.3	163.8	163.3
Melting range (°C)	30.0	34.8	30.0	28.8
S4.	Restabilized material using 0.2 % w/w Recyclossorb 550 + 0.2 % w/w Recycloblend 660, reprocessed at 260°C			
Duration of heat aging	0 h	500 h	1000 h	2000 h
Melting point temperature (°C)	163.2	163.0	161.4	159.8
Melting range (°C)	27.3	29.1	30.0	27.8
S5.	Restabilized material using 0.2 % w/w Recyclossorb 550 + 0.5 % w/w Recycloblend 660, reprocessed at 260°C			
Duration of heat aging	0 h	500 h	1000 h	2000 h
Melting point temperature (°C)	164.6	164.8	163.2	162.9
Melting range (°C)	27.5	28.3	26.6	27.1
S6.	Restabilized material using 0.4 % w/w Recyclossorb 550 + 0.5 % w/w Recycloblend 660, reprocessed at 260°C			
Duration of heat aging	0 h	500 h	1000 h	2000 h
Melting point temperature (°C)	164.2	163.8	164.6	164.5
Melting range (°C)	25.2	27.1	31.9	28.2
S7.	Restabilized material using 0.4 % w/w Recyclossorb 550 + 1.0 % w/w Recycloblend 660, reprocessed at 260°C			
Duration of heat aging	0 h	500 h	1000 h	2000 h
Melting point temperature (°C)	163.4	163.8	164.2	164.0
Melting range (°C)	23.9	29.0	28.6	29.3

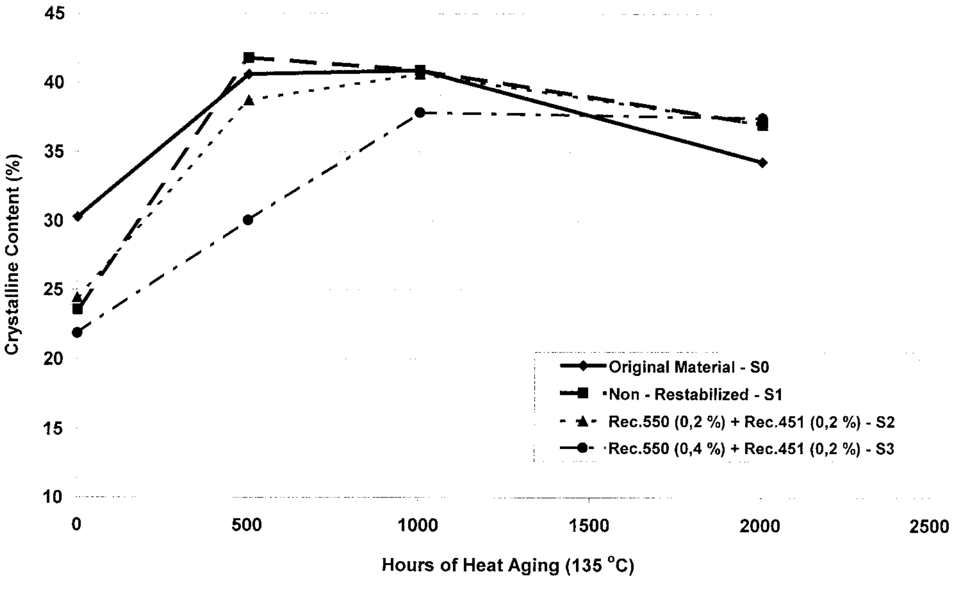


Figure 1 PP-filled chair material reprocessed at 260°C: effect of heat aging on crystalline content—I.

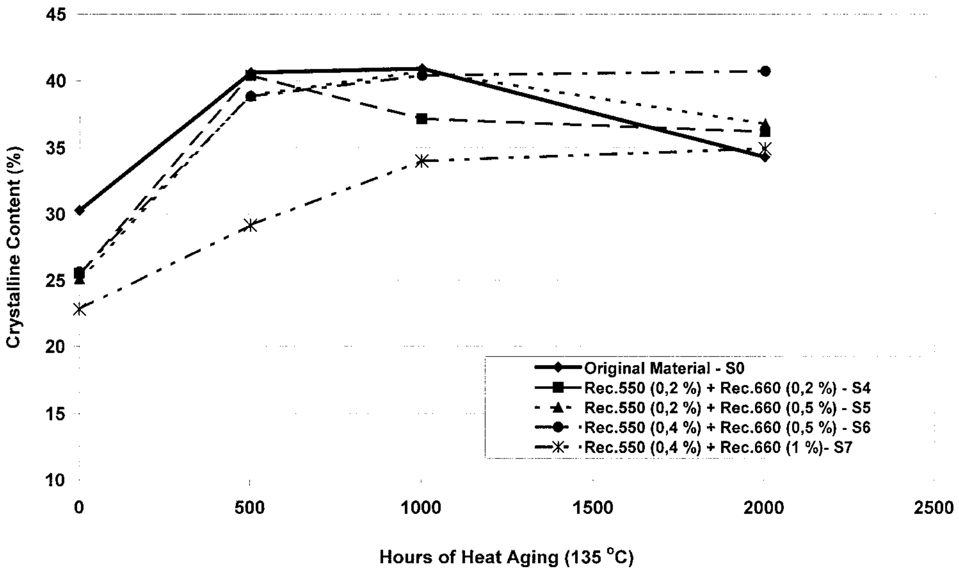


Figure 2 PP-filled chair material reprocessed at 260°C: effect of heat aging on crystalline content—II.

sists of antioxidants, coadditives, and selected oxirane compounds as reactive agents in a specific ratio.

Specimens preparation

A Werner & Pfeiderer ZSK 25 twin-screw extruder and an Arburg 221-75-350 injection-molding machine were used for preparation of specimens. The experimental parameters of the twin-screw extruder were 100 rpm rotation speed and operation temperature at 260 or 280°C, whereas in the injection molding machine temperature and pressure were kept at the levels of 245°C and 50 bars, respectively. Using the twin-screw extruder a single reprocessing cycle was performed to ensure complete homogenization of the additives with the chair material.

Specimens for mechanical tests were prepared in the following 11 qualities:

1. S0: original waste (PP-chairs) material, injection molded without a previous reprocessing step
2. S1: nonrestabilized material, reprocessed at 260°C
3. S2: restabilized material using 0.2% w/w Recy-

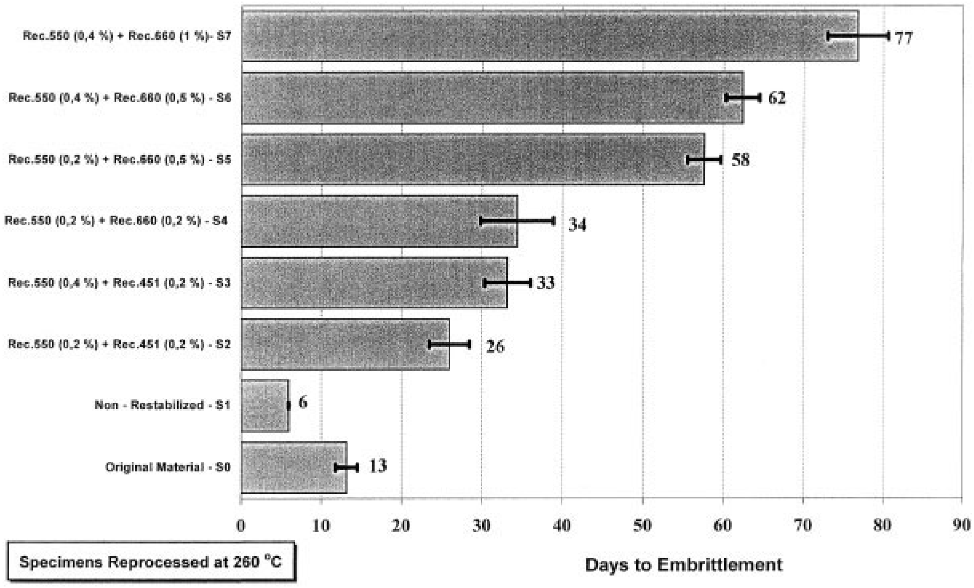


Figure 3 Days to embrittlement of recycled PP-filled garden chairs during heat aging at 135°C. Specimens reprocessed at 260°C.

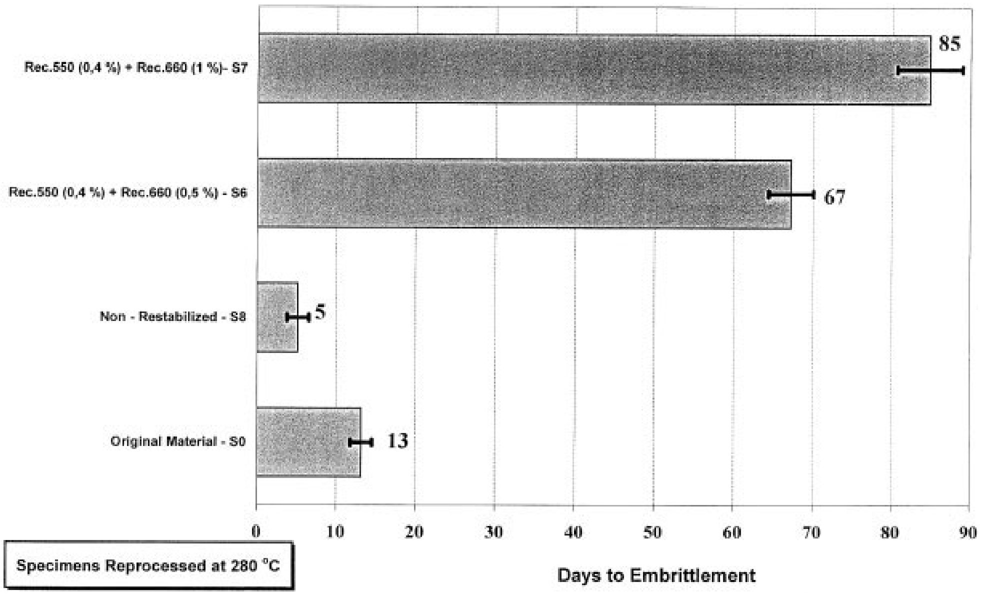


Figure 4 Days to embrittlement of recycled PP-filled garden chairs during heat aging at 135°C. Specimens reprocessed at 280°C.

clossorb 550® and 0.2 % w/w Recyclostab 451®, reprocessed at 260°C

4. S3: restabilized material using 0.4% w/w Recyclossorb 550® and 0.4% w/w Recyclostab 451®, reprocessed at 260°C
5. S4: restabilized material using 0.2% w/w Recyclossorb 550® and 0.2% w/w Recycloblend 660®, reprocessed at 260°C
6. S5: restabilized material using 0.2% w/w Recyclossorb 550® and 0.5% w/w Recycloblend 660®, reprocessed at 260°C
7. S6: restabilized material using 0.4% w/w Recyclossorb 550® and 0.5% w/w Recycloblend 660®, reprocessed at 260°C
8. S7: restabilized material using 0.4% w/w Recyclossorb 550® and 1% w/w Recycloblend 660®, reprocessed at 260°C
9. S8: non-restabilized material, reprocessed at 280°C
10. S9: restabilized material using 0.2% w/w Recyclossorb 550® and 0.5% w/w Recycloblend 660®, reprocessed at 280°C

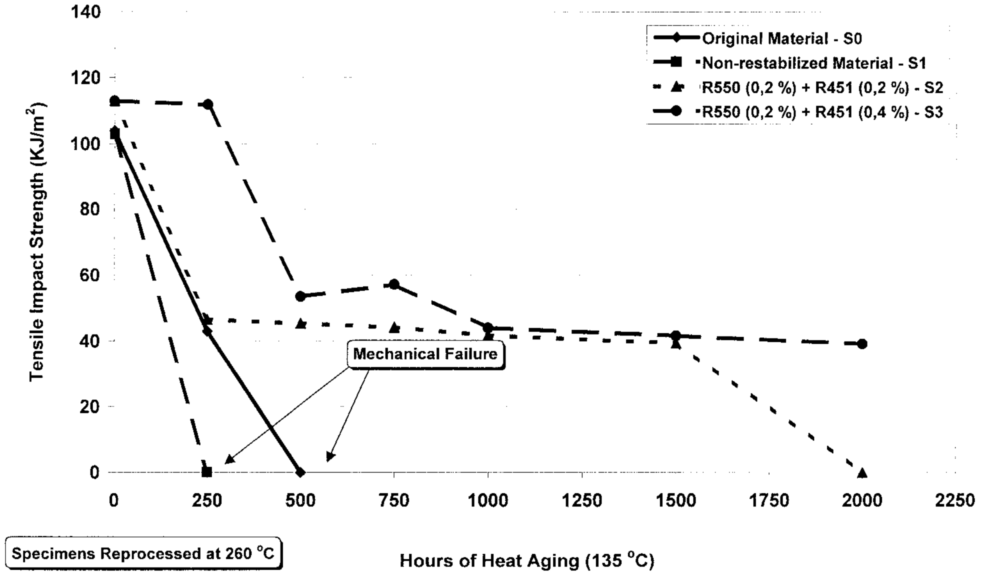


Figure 5 PP-filled chair material reprocessed at 260°C: Effect of heat aging on tensile impact strength—I.

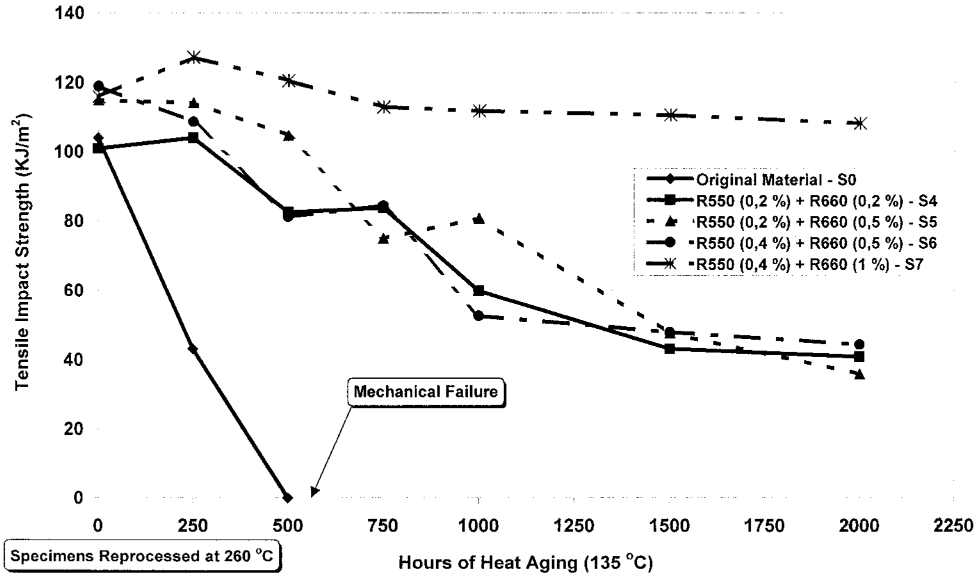


Figure 6 PP-filled chair material reprocessed at 260°C: effect of heat aging on tensile impact strength—II.

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

Oven aging

For the determination of the long-term thermal stability of the recycled chair material, specimens of all different grades were subjected for 2000 h to accelerated heat aging using a circulating air oven, from Memmert Co. The oven temperature was set at 135°C, a temperature that is common for the accelearted heat aging of PP.[17]

DSC measurements

For selected compositions, a Perkin-Elmer DSC-4 calorimeter was used to obtain thermograms of the recycled material during oven aging. The measurements were applied, after 0, 500, 1000 and 2000 h of oven aging.

All runs were carried out in nitrogen atmosphere, using an empty capsule as reference, between 50 and 300°C. Samples weight varied from 4.5 to 5.5 mg, and the heating rate was fixed at the level of 10°C/min.

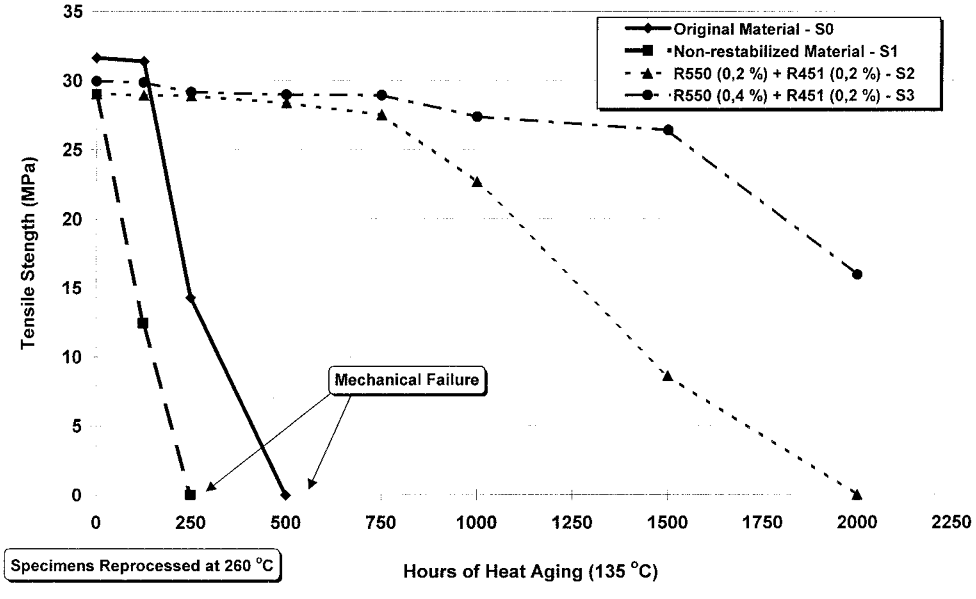


Figure 7 PP-filled chair material reprocessed at 260°C: effect of heat aging on tensile strength—I.

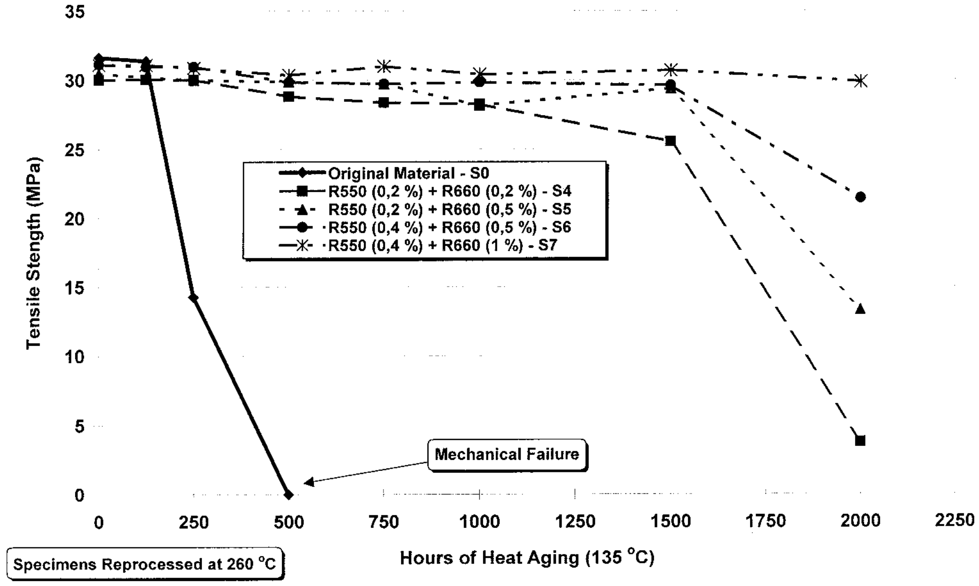


Figure 8 PP-filled chair material reprocessed at 260°C: effect of heat aging on tensile strength—II.

Bending test

For evaluating the long-term thermal stability of the recycled material, a simple bending test until embrittlement was applied daily on all specimens subjected to aging. The lifetime (end point) was reported in days (days to embrittlement). Ten samples of each composition were tested and the average value is reported.

Tensile impact test

To correlate the long-term thermal stability with the mechanical performance tensile impact tests were carried out for all different recipes, after 0, 250, 500, 750, 1000, 1500, and 2000 h of oven aging, according to the ISO 8256-1990 standard method. Five samples of each grade were tested. The average value of the five samples is reported. The coefficient of variation [c.v. = (standard deviation/average) × 100] was equal to 6%.

A Zwick PSW 5101 tensile impact tester was used in standard laboratory atmosphere. The initial potential energy of the hammer was 25 J and the velocity at impact was 3.4– 4.1 m/s.

Tensile test

The mechanical performance was further evaluated by applying tensile tests during aging. An Instron 4466

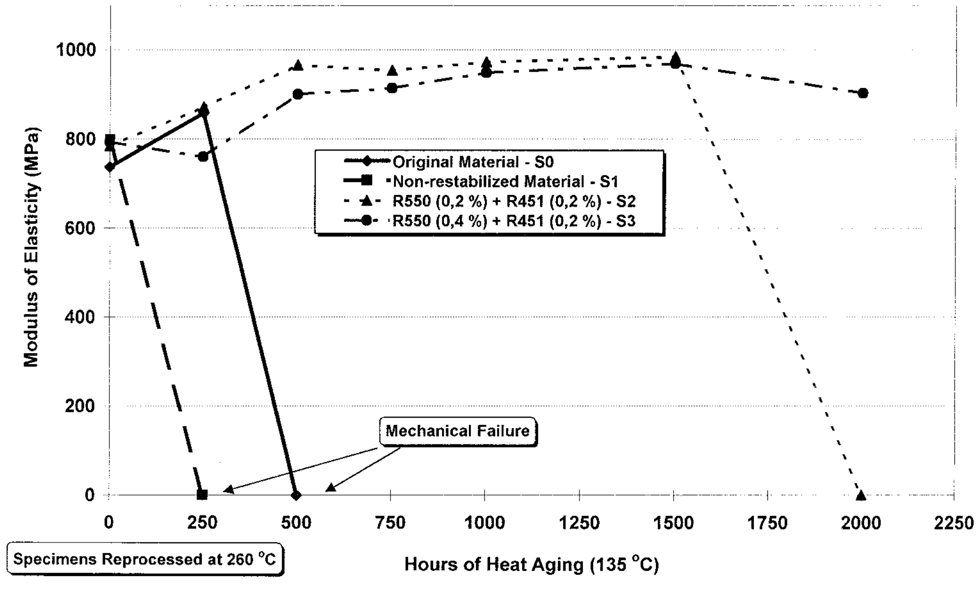


Figure 9 PP-filled chair material reprocessed at 260°C: effect of heat aging on modulus of elasticity—I.

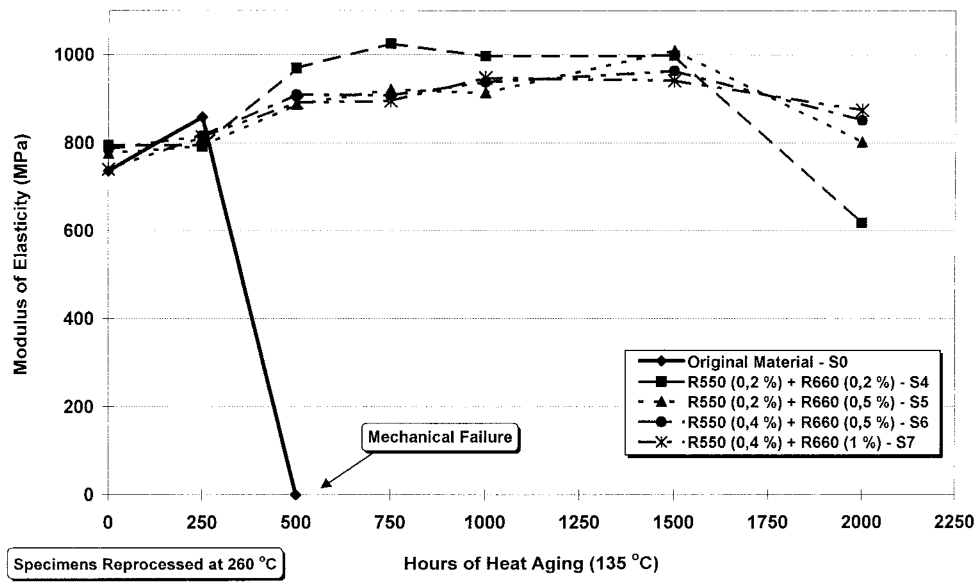


Figure 10 PP-filled chair material reprocessed at 260°C: effect of heat aging on modulus of elasticity—II.

tensile machine according to D638-1976 ASTM method was used, in standard laboratory conditions, while the rate of extension was equal to 50 mm/min. Again, five samples of each composition were tested and the average value of the five samples is reported. The coefficient of variation (c.v.) of the tensile strength, modulus of elasticity, and elongation at break data were found equal to 3, 6.5%, and 9%, respectively.

The aforementioned tensile tests were repeated, for all different compositions, after 0, 125, 250, 500, 750, 1000, 1500, and 2000 h of oven aging.

Microscopic surface examination

For selected compositions surface microphotographs were obtained, in a Leitz Aristamet optical microscope from Leica Co., after 0, 500, and 2000 h of aging, to monitor the effect of heat aging on the surface of the recycled material.

RESULTS AND DISCUSSION

DSC measurements

DSC runs were performed to study the effect of heat aging on the thermal behavior and the crystalline content of the recycled material. On the one hand, DSC runs can reveal modifications on the thermal profile of the recycled material during melting, for example, melting point and melting range temperatures. On the other hand, it is well known that the heat of fusion is the amount of energy necessary in transforming a

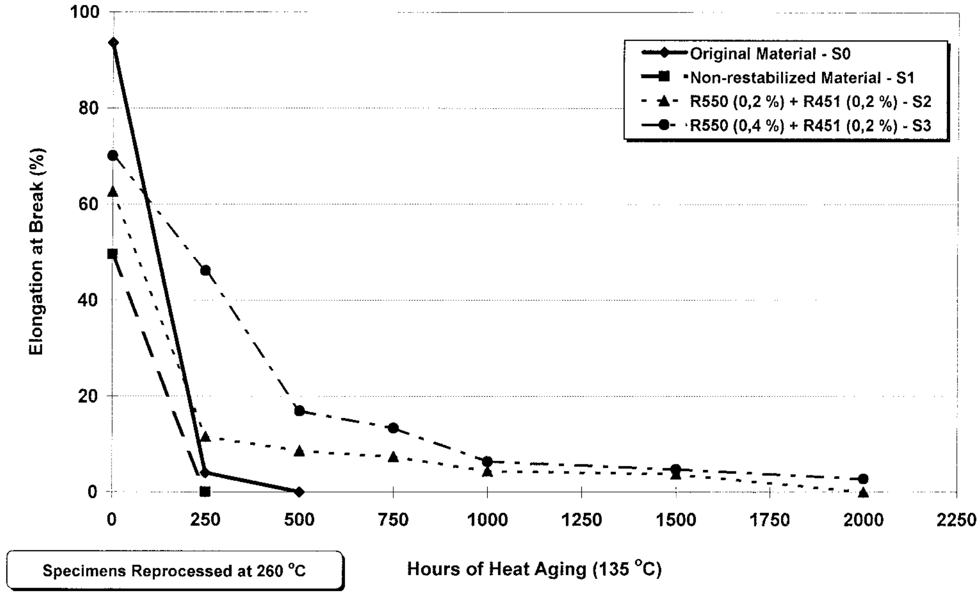


Figure 11 PP-filled chair material reprocessed at 260°C: effect of heat aging on elongation at break—I.

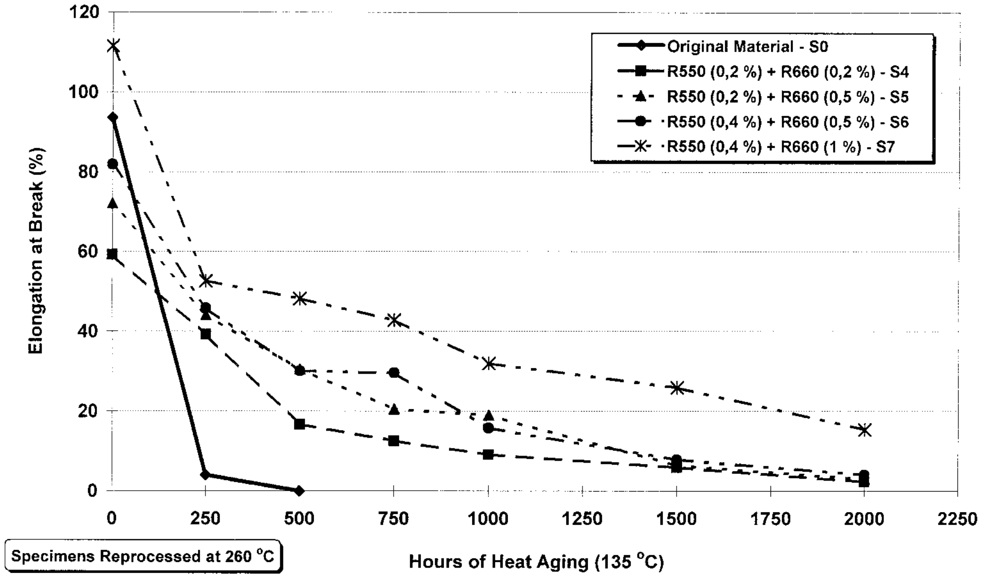


Figure 12 PP-filled chair material reprocessed at 260°C: effect of heat aging on elongation at break—II.

polymer from a crystalline or partially crystalline state to a completely disordered amorphous state. Valid heat effects of a physicochemical process can be estimated by measuring the area under a well-defined DSC thermogram peak. If the heat of fusion ΔH_f of a perfectly crystalline PP is known, the percentage of crystallinity (x) of the recycled material can be derived as follows:

$$x = (\Delta H_{exp}/\Delta H_f) \times 100$$

where ΔH_{exp} is the actual heat of fusion of the sample tested. For PP, ΔH_f is taken equal to 213,19 J g^{-1} (50.91 cal g^{-1}).[24]

It should be mentioned that the measured heat of fusion was corrected for the filler content assuming no deviation from the average content of 15%.

Following this approach, DCS measurements were performed in seven different qualities (S1–S7) of the recycled chairs material, reprocessed at 260°C, as well as in the original waste material (S0) as reference. Data for the melting point and melting range temperatures are summarized in Table I, while the effect of heat aging on the crystalline content, for all different samples studied, is demonstrated in Figures 1 and 2.

As can be seen in Table I, the melting point for the original waste (S0) and the nonrestabilized material (S1) decreases already after the first 500 h of heat aging. This view is probably associated with chain scission phenomena occurring in the nonprotected (nonrestabilized) samples, due to thermo-oxidation. Chain scission results in decreasing the molecular weight and the crystal size of the polymer matrix, leading in this way to modifications in the melting behavior of the chair material. The addition of stabilization agents in the material affects the aforementioned degradation effect, eliminating practically the decrease of the melting temperature in all restabilized grades.

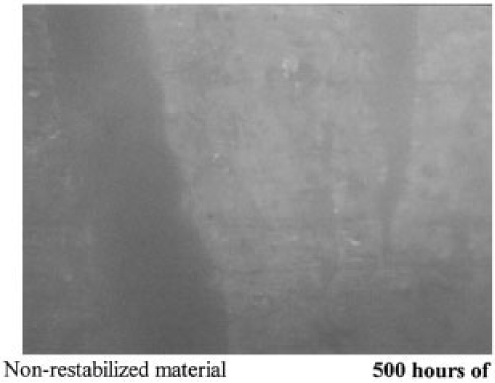
On the other hand, studying the melting range data, restabilized samples show in general a somewhat broader melting range, which might correspond again to higher molecular weights and broader molecular weight distributions. The narrower melting range of the degraded polymer might be explained that lowering the molecular weight is accompanied by narrowing of the molecular weight distribution.[25]

Figures 1 and 2 indicate that heat aging results in a gradual increase of the crystalline content, more severe in the beginning, for all different qualities studied. This could be correlated with an annealing effect, which leads in a molecular reorientation of the polymer crystals and it is also accompanied by crystal growth.[26] However, as the aging time further increases, the crystalline content of the nonrestabilized grades (S0, S1) gradually decreases, probably due to the aforementioned chain scission effect on the crystal size. Obviously, this is not the case for the restabilized grades, where a leveling off in the crystalline content is mainly recorded.

Bending test

The time to brittleness corresponding to the total loss of mechanical properties under accelerated heat aging conditions (days to embrittlement), for all different compositions reprocessed at 260°C, is demonstrated in Figure 3. As can be seen, thermo-oxidative degradation occurring during heat aging affects dramatically the long-term thermal stability of the nonprotected samples (S0 and S1), resulting in a very short life span under bending test mode. This phenomenon is very significantly delayed when restabilization additives are employed, but the type and the level of the restabilization systems employed are still crucial. The achieved lifetime corresponds clearly to the overall stabilizer quantity and the quantity of the filler deactivator. For example, the addition of the filler deactivator (Recycloblend 660®) in the level of 1% w/w (S7), prolongs the thermal stability of the recycled material by almost 14 times. Finally, the same view is also observed in the case of samples reprocessed at 280°C, plotted in Figure 4, where the stabilized materials are not affected by the higher processing temperature and show the same range of stability.


(a) Non-restabilized material **0 hours of heat aging**


(b) Non-restabilized material **500 hours of heat aging**


(c) Non-restabilized material **2000 hours of heat aging**

Figure 13 PP-filled chair nonrestabilized material (S1): effect of heat aging on the surface condition.

Tensile impact test

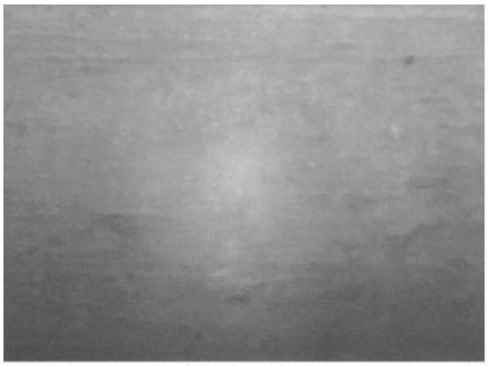
Figures 5 and 6 illustrate the effect of heat aging on the tensile impact strength of the recycled chair material, for all different grades reprocessed at 260°C. As can be seen, the samples of the original chair material (S0) and nonrestabilized material (S1) failed after a very short exposure period, i.e., before completing 500 and 250 h, respectively. The reduced stability of S1 reflects the influence of the reprocessing step. However, it should be mentioned that in both cases, the test specimens became completely brittle, without any mechanical resistance, reflecting severe degradation in the polymer chains due to thermo-oxidation.

In contrast with the aforementioned picture, all the restabilization recipes employed result in improving significantly the long-term thermal stability of the recycled PP-filled chair material. However, the data plotted in Figures 5 and 6 reveal that the restabilization recipe plays a very important role in maintaining the initial property value, probably more important than in an unfilled system. In particular, the addition of the heat and processing stabilizer system Recyclostab 451®, together with the light stabilizer system Recyclossorb 550® alone (S2 and S3 in Fig. 5), results in poor retention of the tensile impact strength, although high molecular weight HALS stabilizers (ingredients a.o. of Recyclossorb 550) should contribute to extension of heat stability. Note that after 500 h of heat aging the restabilization grades S2 and S3 have lost more than 50% of the original value. On the contrary, the synergistic action of the Recyclossorb 550® with the specially designed system Recycloblend 660®, which acts also as filler deactivator (Fig. 6), yields higher property retention. Furthermore, it should be noted that the addition of Recycloblend 660®, in the higher concentration of 1% w/w (S7) can control completely the thermo-oxidative degradation of the recycled chair material, ensuring its long-term thermal stability and resulting in an excellent retention of the tensile impact strength even after 2000 h of heat aging. In other words, the use of the filler deactivator in an optimized amount can limit the consumption of the antioxidants due to the filler presence and thus protect the mechanical performance of the recycled material during heat aging. The same view was encountered for the samples reprocessed at 280°C.

Tensile strength test

The influence of heat aging on the tensile strength at yield of all different grades reprocessed at 260°C is presented in Figures 7 and 8. For the original waste and nonrestabilized grades (S0, S1), aging-induced oxidation affects dramatically the polymer morphology, resulting in an extremely brittle material, after a very short exposure period of approximately 250 h or even

(a) Restabilized (0,4 % w/w Rec.550$^{®}$ and 1 % w/w Rec.660$^{®}$) **0 hours of heat aging**



(b) Restabilized (0,4 % w/w Rec.550$^{®}$ and 1 % w/w Rec.660$^{®}$) **500 hours of heat aging**

(c) Restabilized (0,4 % w/w Rec.550$^{®}$ and 1 % w/w Rec.660$^{®}$) **2000 hours of heat aging**

Figure 14 PP-filled chair restabilized material, using 0.4% Recyclossorb$^{®}$ 550 and 1.0% Recycloblend$^{®}$ 660 (S7): effect of heat aging on the surface condition.

less. This can be successfully avoided by the addition of the restabilization systems employed, but for even better results the appropriate compositions should be chosen. In fact, the best performance is encountered again by using the filler deactivator in an appropriate level (S7), which ensures excellent retention of the tensile strength at yield even after 2000 h of heat aging. As expected increasing levels of stabilizers prolong the performance.

Figures 9 and 10 present the influence of heat aging on the modulus of elasticity for all different grades reprocessed at 260°C. In all cases, with the exception of the nonrestabilized grade, which fails completely, a slight improvement in the modulus of elasticity can be observed at the early stages of heat aging, caused by the annealing effect, and is in line with the increase of crystalline content. For longer exposure times the elastic modulus retention can only be achieved by adding the optimum stabilizers composition.

The influence of heat aging on elongation at break of the eight different grades reprocessed at 260°C is plotted in Figures 11 and 12. Heat aging results in a dramatic reduction of the elongation at break, especially at the early stages of the process. This behavior is well correlated with the morphological changes induced in the polymer structure, affecting elongation performance by promoting brittleness.[6] The latter phenomenon seems much more intensive for the nonrestabilized grades (S0, S1), which become totally brittle after a very short aging period (500 h or even less). On the other hand, the stabilization systems employed appear to moderate the aforementioned negative effect leading to higher elongation values, but still stabilization level and stabilization type remain crucial.

Finally, the same view for the tested tensile properties is also observed in the case of samples reprocessed at 280°C, which is in line with the results of time to embritllement in the bending test.

Microscopic surface examination

The microphotographs in Figure 13(a)–(c) present the evolution of the surface conditions for the nonrestabilized recycled material (S0) during the oven-aging test. As can be seen, already after 500 h the surface suffers from crack formation due to thermo-oxidation. For longer aging times the number and the size of the cracks further increase, and after 2000 h of oven aging the surface seems totally destroyed (degraded) by continuous rifts (deep cracks), which corresponds to the complete loss of mechanical properties shown in the previous chapters.

The microphotographs in Figure 14(a)–(c) present the surface condition of restabilized material containing 1% w/w from the filler deactivator (Recycloblend 660®) and 0.4% w/w of Recyclossorb 550® (composition S7). It is very impressive that this additive combination increases the long-term thermal stability of the recycled material in a way that the surface remains free from crack formation even after 2000 h of oven aging.

The same view was also observed in the most cases of the restabilized grades, clearly in dependence of the stabilizer/deactivator composition and concentration.

CONCLUSIONS

Oven aging, for about 2000 h, was applied to study thermo-oxidation effects on recycled, postused, $CaCO_3$-filled PP garden chairs. Chain scission phenomena occurring during aging reduce the crystallinity content and modify the melting behavior of the chair material resulting finally in material embrittlement. Additionally, mechanical tests data clearly demonstrate that the performance of the nonrestabilized material is irreversibly deteriorated. On the contrary, the addition of the optimized restabilization system improves significantly the long-term thermal stability of the recycled material resulting eventually in remarkable retention of all mechanical properties tested. Tensile strength, tensile impact strength, elongation, and modulus can be maintained at a high level. Furthermore, the appropriate restabilization recipe eliminates effectively the crack formation on the surface of the recycled material by protecting the polymer from the damaging effect of oxidative degradation during heat aging. Consequently, exposure in oven aging proved that restabilization is mandatory for the long-term thermal stability of the old chair material, ensuring its reuse in the original application.

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