

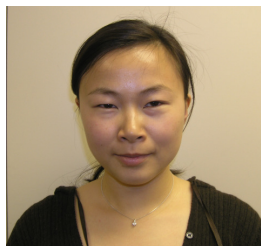


CLARITY & NUCLEATION FOR POLYPROPYLENE – A NEW BENCHMARK

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BIOGRAPHICAL NOTE



Hieu-Dinh PHAN graduated from the Engineering School of Chemistry, Physics and Electronics (CPE Lyon) in France in 2005. As part of this Master of Chemistry degree course one year was spent as an Erasmus student at UMIST (University of Manchester Institute of Science and Technology).

She joined RiKA International Limited in 2005. At present she is a Senior Polymer Chemist and is based in Manchester, where she is involved in the research and product development of clarifiers and nucleators for polypropylene.

ABSTRACT

The paper will present data demonstrating new technology, RiKACLEAR PC1, that offers the polypropylene industry a new innovative clarifier for homopolymer and random copolymer, as well as a nucleator that gives balanced impact and stiffness properties when used as a nucleator in non-clear applications.

Current systems are mainly based on acetal sorbitol chemistry which gives acceptable clarity but can cause severe taste and odour issues especially in thin walled applications. These acetal sorbitol compounds are well known to hydrolyse during processing, causing elution of free aldehyde from the mouldings.

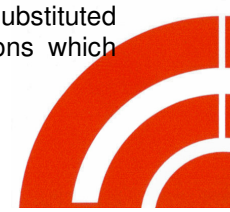
This paper clearly demonstrates the accomplishments of this innovative clarifier comparing its performance with conventional clarifiers and other newly developed nucleators of polypropylene in a range of systems including homopolymer, random copolymer, block copolymers and controlled rheology grades. Using PC1 as a clarifier, the paper will present data showing extremely low haze values and an exceptional balance between clarity and stiffness. As a nucleator in non-clear applications, data for PC1 will demonstrate that even at low concentrations (~500ppm), excellent stiffness and impact properties can be obtained as well as maintaining impact strength at low temperatures.


INTRODUCTION

The versatility and cost efficiency of polypropylene have historically made it a polymer of choice in many applications. Most of these applications consist of parts made by injection moulding. Well known end-uses include housewares, storage containers and disposable medical syringes.

Today's injection moulded articles require a balance of clarity, stiffness and toughness. The optics (haze and gloss) of the articles, especially for thin wall injection moulded applications, are important to provide better aesthetics for consumer appeal and "see-through" functionality. Additionally, high modulus is required for these applications to improve the stiffness and to allow for lighter weight articles. Finally, improved toughness is also important both at room temperature and at zero degrees temperatures to provide better resistance all through the life of the part. Conventional clarifiers and nucleators of polypropylene historically have provided an acceptable level of performance, but not the optimum balance that the industry demands

RiKA International Limited offers the polypropylene industry a new clarifier, RiKACLEAR PC1. It differs from those currently used in that it is based on new chemistry. RiKACLEAR PC1 is the first non-sorbitol based clarifier that meets all of the polypropylene industries' requirements. The main goals of the development of this product were high clarity, high stiffness, high impact strength, high heat resistance and no taste and odour issues. As the inventors of acetal sorbitol chemistry, the R&D staff at NJC were only too aware that the mono-substituted molecule and indeed the di-substituted molecule had a tendency to degrade under certain conditions which





caused taste and odour problems especially in thin walled articles. It was therefore a cornerstone of the development project to identify a chemical compound that was not based on old technology.

PC1 provides superior transparency compared with the current industry standard and higher stiffness is also achieved by using this clarifier without lowering impact strength and heat resistance. Therefore PC1 gives an exceptional balance between clarity and stiffness. In addition, the inclusion of PC1 in all polypropylene systems, including rheology grades, shows no signs of degradation and does not affect the organoleptics of the finished articles.

This paper demonstrates the accomplishments of this innovative clarifier, comparing its performance with conventional clarifiers and nucleators of polypropylene and other newly developed chemicals in a range of systems including homopolymers, random copolymers, impact copolymers and controlled rheology grades (vis-breaking process).

EXPERIMENTAL

Materials: All formulations contained a standard base stabilization system. In the controlled rheology grades, different concentrations of the peroxide Trigonox 101 (2,5-Dimethyl-2,5-di(tert-butylperoxy)hexane) by Akzo Nobel Polymer Chemicals were added with the stabilizers and nucleating agents prior to extrusion.

An un-nucleated sample (BLANK), two organophosphate metal salts (PHOSPHATE SALT A and PHOSPHATE SALT B), bis(3,4-dimethyl benzylidene) sorbitol (3,4-DMDBS) and 1,3,5-tris(2,2-dimethylpropanamido)benzene (DMPAB) were used to compare with the newly developed clarifying agent RiKACLEAR PC1.

Polypropylene used was a typical ethylene-propylene random copolymer having ethylene content of ca. 3.2wt% with a melt flow rate (MFR) of ca. 13g/10min. The polypropylene homopolymer used in the evaluation of PC1 was with a MFR of 12g/10min, and the polypropylene block copolymer with a MFR of 35g/10min.

Processing: All samples were mixed with a specified amount of nucleating agent using a Thermo Prism Pilot 5 high speed mixer with a rotating blade, followed by extrusion with a Thermo Prism twin-screw extruder (L/D=28) and pelletization. In these evaluations the extrusion temperature was held at 250°C. The injection moulding was performed with a melt temperature of 230°C and a mould temperature of 40°C.

Thermal analysis: The crystallization temperature of polypropylene was determined by using a Mettler Toledo DSC 822 differential scanning calorimeter (DSC) under nitrogen. Samples of 3-5mg were heated up to 240°C, held for 3 minutes, and cooled at -10°C/min to 25°C.

Mechanical & optical properties: Mechanical and optical tests for injection moulded parts were carried out according to the relevant ISO and ASTM (Haze measurements) methods.

RiKACLEAR PC1 AS A CLARIFIER IN POLYPROPYLENE RANDOM COPOLYMER

Polypropylene (PP) is a semi-crystalline material. PP normally crystallizes slowly, and when the molten polymer cools, the growth of these crystals is generally initiated around microscopic “defects” naturally present in the material. With time, these crystals radiate outward from these nucleating centres forming spherical structures known as spherulites. As spherulites grow until they meet another crystal, their size is dependent on the number of nucleation sites within the crystallizing polymer [1] [2]. Since the spherulites scatter light, un-nucleated polypropylene manifests poor see-through clarity. The addition of a clarifier to PP is equivalent to introducing “artificial defects” around which spherulites can initiate their growth. Consequently, adding a high performance clarifier results in the spherulites to become smaller than the wavelength of light, so that the light scattering is considerably reduced and the clarity of the material is significantly improved.

The crystallizability of the chains is one factor that determines how thick the crystallites will be, and the thickness of the crystallites determines how much heat energy is required to melt them (melting point). In random copolymer, ethylene monomers are added. These ethylene monomers act as “defects” in the chain regularity that prevent large spherulites from forming during crystallization. As the ethylene content increases, the crystallite thickness gradually decreases, and this results in a lower melting point [3].

As can be clearly seen from **Figure 1**, PC1 reduced the haze levels in 0.5mm plaques at 1500ppm and 2000ppm, compared to the blank resin, 3,4-DMDBS, DMPAB and particularly PHOSPHATE SALT A. This improvement in haze using lower levels of PC1 will enable cost-effective improvements in the design of clarified polypropylene. In the case of 1mm plaques, haze level for PC1 at 2000ppm was comparable to that of 3,4-DMDBS.

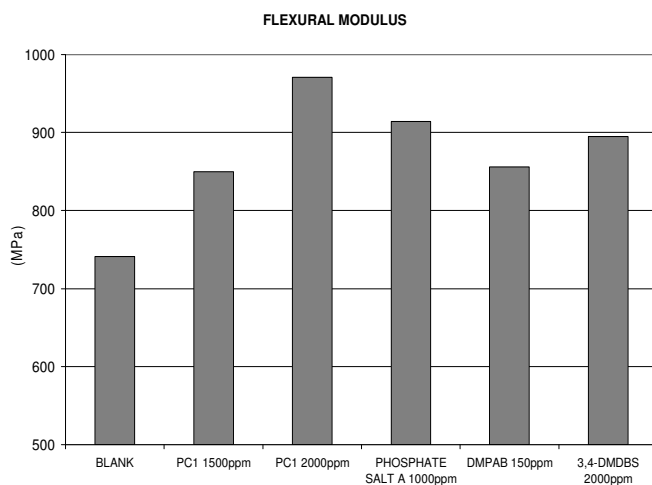
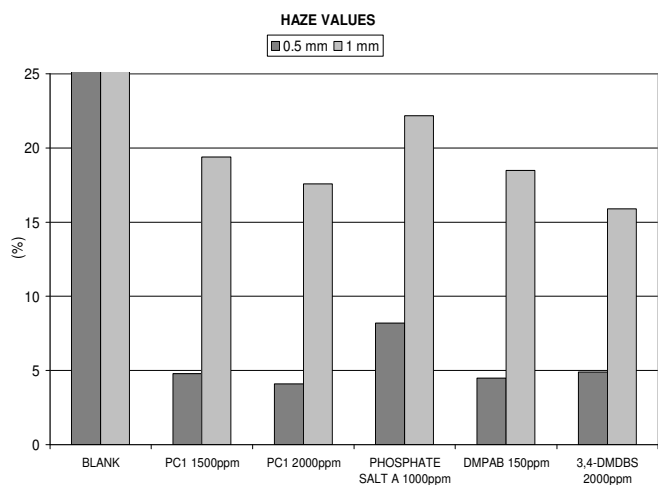


Figure 1. Haze measurements in 0.5mm & 1mm plaques

Figure 2. Flexural modulus in RACO

An important feature of PC1 along with its clarifying properties is the higher stiffness it confers to the material. **Figure 2** showed the improvement in flexural modulus achieved with the addition of PC1 when compared to the blank resin, PHOSPHATE SALT A, DMPAB and 3,4-DMDBS, especially at 2000ppm.

Consequently, PC1 can improve not only the transparency, but also the stiffness of the material.

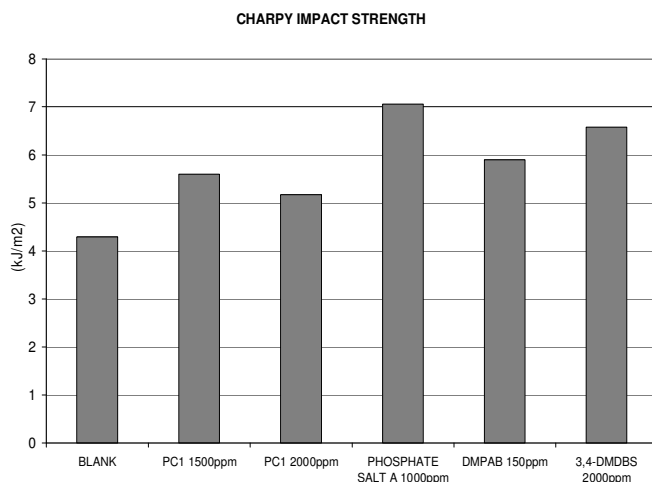
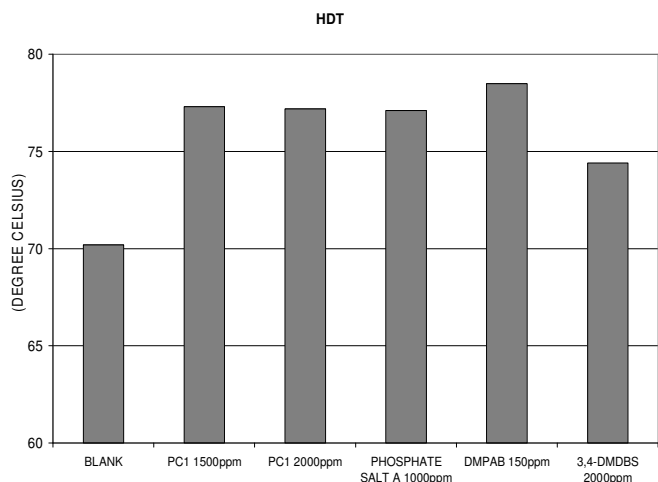


Figure 3. Heat Distortion Temperature in RACO

Figure 4. Charpy IS at RT in RACO (notched)

Furthermore, the high stiffness that PC1 offered was also associated with a high heat resistance (**Figure 3**). Both HDT values of PC1 were much higher than that of 3,4-DMDBS and similar to those of PHOSPHATE SALT A and DMPAB.

Concerning the impact strength (IS), both Charpy impact strength values for PC1 were superior to that of the blank sample and comparable to that of DMPAB (**Figure 4**). Charpy values were, however, lower compared to those of the PHOSPHATE SALT A and 3,4-DMDBS.

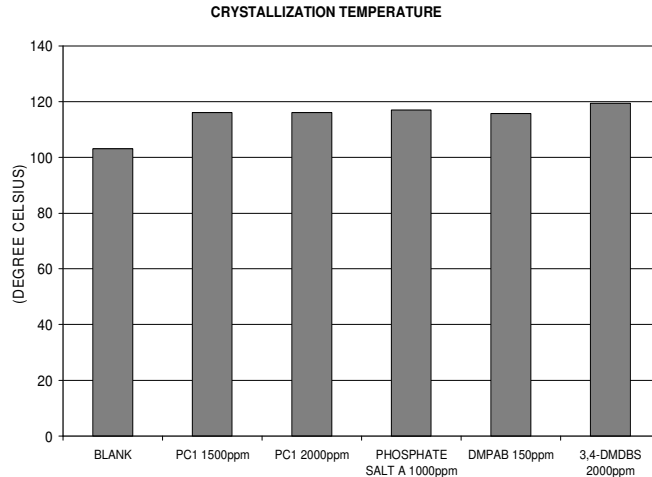


Figure 5. Crystallization temperature in random copolymer

The introduction of foreign nuclei to the polymer melt dramatically speeds up the rate of crystallization. As it can be seen in **Figure 5**, an increase in the crystallization temperature was observed for PC1, and this had the effect of reducing cycle time in injection moulding.

In addition to the superior optical and mechanical properties shown above, PC1 has the ability to improve productivity by exhibiting higher crystallization temperature for both loading levels.

RIKACLEAR PC1 AS A CLARIFIER IN CONTROLLED RHEOLOGY GRADES (PP RANDOM COPOLYMER)

In injection moulding, the heated and softened material is forced into a mould and the way in which the material flows is very important. Controlled rheology (CR) PP is produced by vis-breaking process (viscosity breaking): peroxides are mostly used and they are added with stabilizers and other additives prior to extrusion and pelletization. These CR resins have higher melt flow rate (MFR), lower molecular weight (MW), narrower molecular weight distribution (MWD) and consequently they exhibit an easier and more consistent flow. When a peroxide and a PP polymer mixture is heated, the peroxide will produce free radicals that react with the PP molecules. In the CR process the peroxide attacks randomly, and statistically the longest molecules are most susceptible to be attacked. This results in a narrow MW distribution and increased MFR. Controlled rheology grades (CRG) are designed to combine very high fluidity while maintaining a high stiffness-impact balance.

With a view to evaluating the robustness of PC1 in the presence of a peroxide, and if degradation of the clarifier could take place in these circumstances, 100ppm and 500ppm of Trigonox 101 were added to formulations containing different concentrations of PC1. The optical and mechanical properties of the material were then assessed.

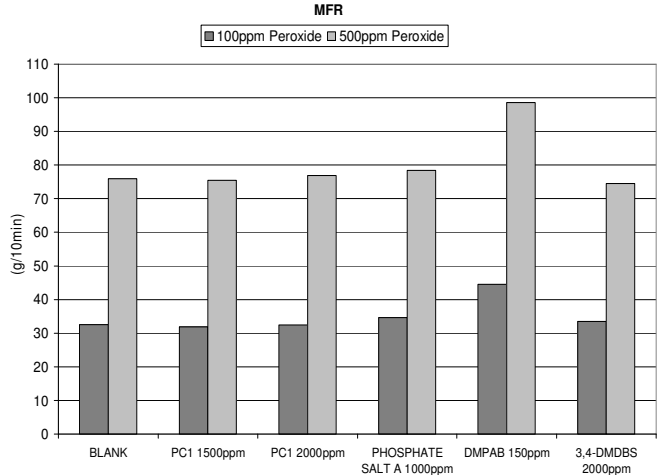


Figure 6. Melt flow rate when adding 100ppm & 500ppm of Trigonox 101

Figure 6 showed the increase on melt flow rate when 100ppm and 500ppm of peroxide were added to the formulation, leading to materials with MFR of 32g/10min and 75g/10min respectively.

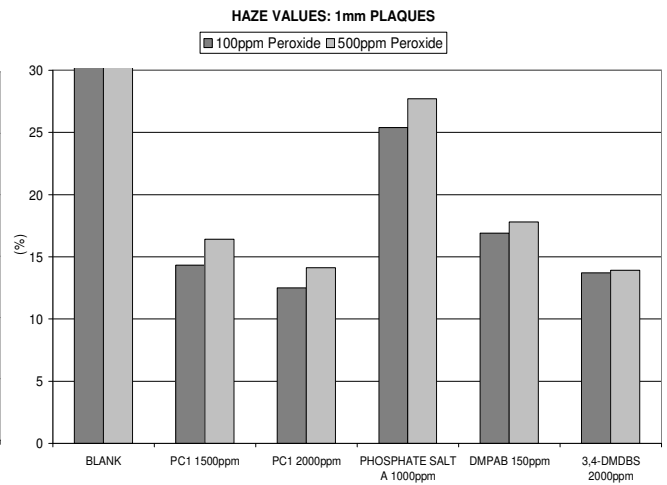
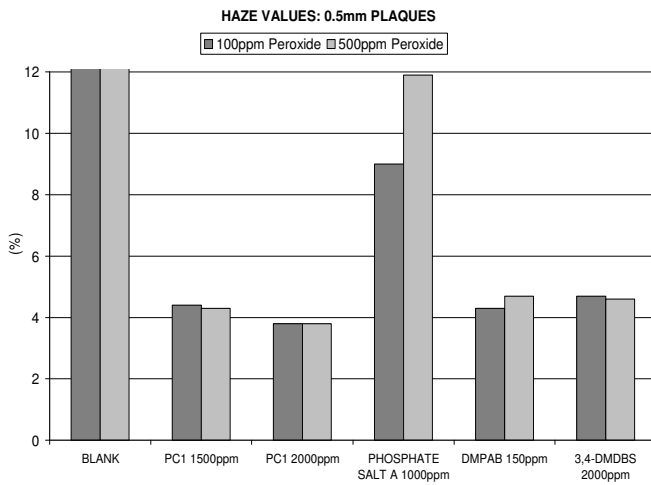


Figure 7. Haze measurement for 0.5mm plaques in CRG **Figure 8. Haze measurement for 1mm plaques in CRG**

It is also important in controlled rheology grades to achieve a high level of clarity in the final product, as these grades are commonly used for thin wall packaging in food (dairy and confectionery) and non food applications (cosmetics and electronics).

The haze in 0.5mm and 1mm plaques was measured when the peroxide was added and the results shown in **Figure 7 & 8**. For 0.5mm thickness plaques, low haze values were maintained for PC1, which ruled out any degradation of PC1. For 1mm plaques, the haze increased slightly, but still within acceptable limits as the results remained comparable to 3,4-DMDBS and lower than those of PHOSPHATE SALT A and DMPAB.

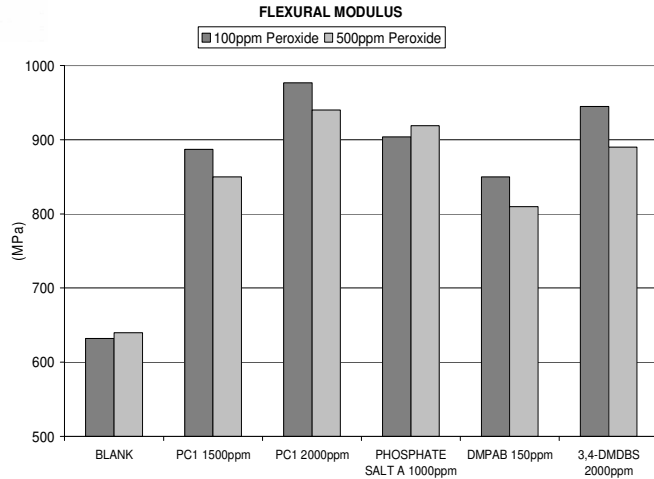


Figure 9. Flexural modulus in RACO-CRG

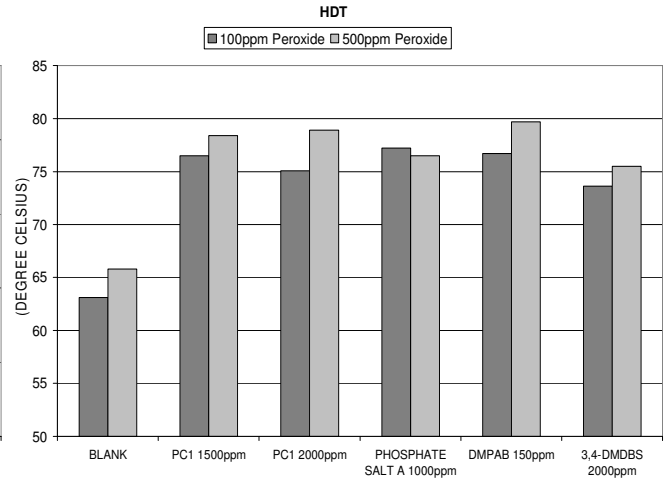


Figure 10. Heat Distortion Temperature in RACO-CRG

When the peroxide attacks the long chains, the most immediate effect is the reduction in the length of the polymer chain and associated with this, a reduction in the stiffness. **Figure 9** showed a slight drop in stiffness for all nucleated samples, except for the PHOSPHATE SALT A. However a reduction in the flexural modulus of only 4% or less was observed for PC1, whereas other commercial clarifiers exhibited a greater decrease of stiffness in the presence of peroxide.

Together with the stiffness, an important reduction in the chain length could lead to a substantial decrease in the heat resistance. The results obtained in **Figure 10** demonstrated that not only materials containing PC1 did not suffer a decrease in the heat resistance, but on the contrary, a small increase of the HDT was observed.

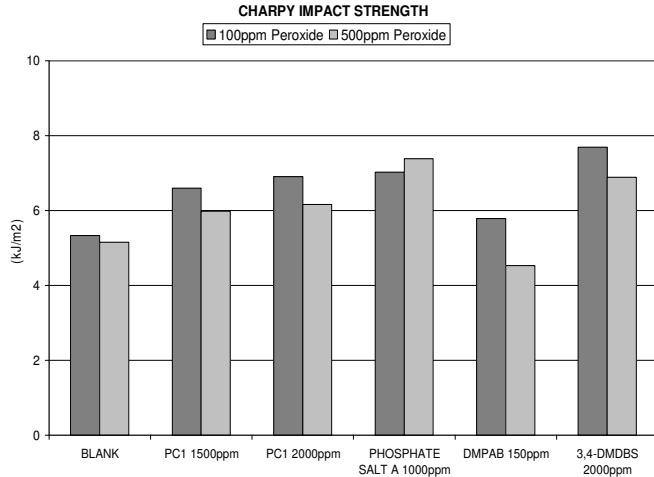


Figure 11. Charpy IS at RT in RACO-CRG (notched)

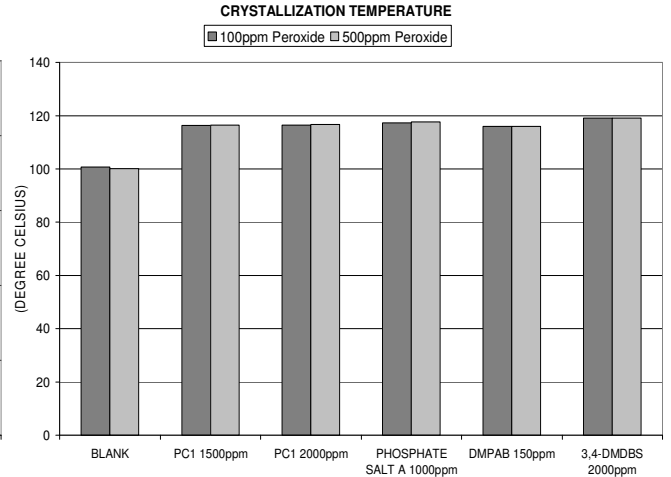


Figure 12. Crystallization temperature in RACO-CRG

Equally important in controlled rheology grades is to maintain the impact-stiffness balance of the material. The impact strength values for Charpy reported in **Figure 11** showed that this equilibrium was retained and that the loss of impact strength for PC1 was lower than those of 3,4-DMDBS and DMPAB in the presence of peroxide. However, it seems that the Charpy impact strength of the PHOSPHATE SALT A increased slightly as more peroxide were added to the formulation.

No sign of degradation was observed either in the crystallization temperatures recorded in **Figure 12**, with PC1 providing a significant increase in the Tc in the presence of the peroxide compared to the unnucleated material. Therefore, it is clear from these results that the Tc is not affected in controlled rheology grades.

In summary, the inclusion of PC1 in controlled rheology grades shows no signs of degradation in the optical and mechanical properties of the material.

RIKACLEAR PC1 AS A CLARIFIER IN POLYPROPYLENE HOMOPOLYMER

Homopolymer polypropylene is the most widely used polypropylene material in industry. Its high stereoregularity leads to high levels of crystallinity of around 60-70%, with a melting point of about 160°C. As a result of this high crystallinity, homopolymer PP shows excellent rigidity at room temperature and high heat resistance [3].

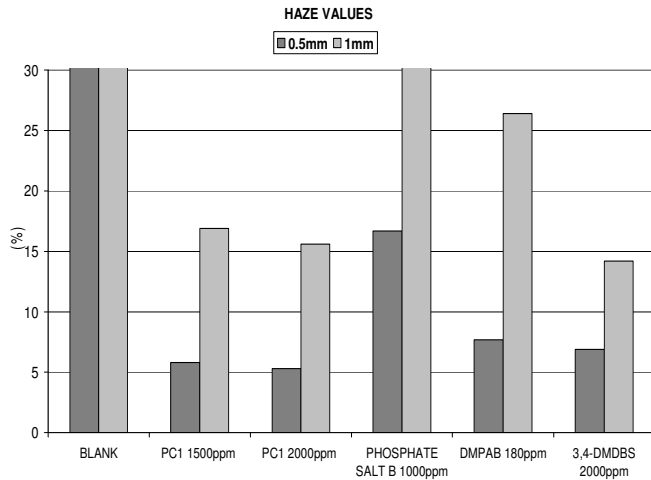


Figure 13. Haze in homopolymer PP

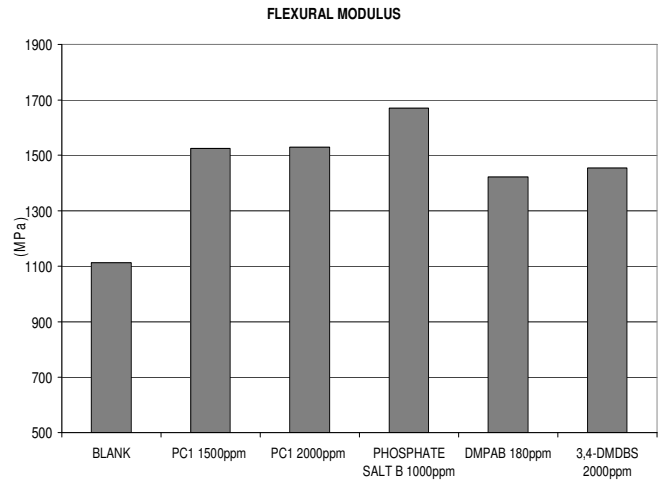


Figure 14. Flexural modulus in homopolymer PP

In order to assess the effect on the clarity of PC1 in homopolymer PP, plaques of 0.5mm and 1mm thickness were injection moulded and their haze measured (**Figure 13**). All PC1 addition levels reduced the haze in the material compared to that of 3,4-DMDBS, DMPAB and the PHOSPHATE SALT B in 0.5mm plaques. In the case of 1mm plaques, PC1 at 2000ppm exhibited a similar performance to that of 3,4-DMDBS, and still lower haze values than those of DMPAB and PHOSPHATE SALT B.

As mentioned before, one of the most important features of PC1 is the high stiffness associated with this excellent clarifier. In **Figure 14** the stiffness of the injection moulded parts containing different levels of PC1 was evaluated. Substantial improvement in the stiffness of all PC1 concentrations was observed when compared to the blank, DMPAB and 3,4-DMDBS. However, the stiffness provided by the PHOSPHATE SALT B was slightly higher than that of PC1 at any given concentrations.

These results confirm once more that PC1 perfectly balances transparency and stiffness compared to 3,4-DMDBS, PHOSPHATE SALT B and DMPAB.

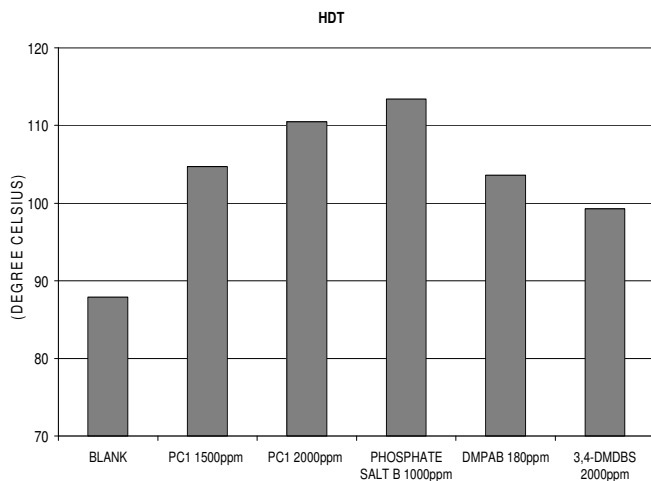


Figure 15. HDT in homopolymer PP

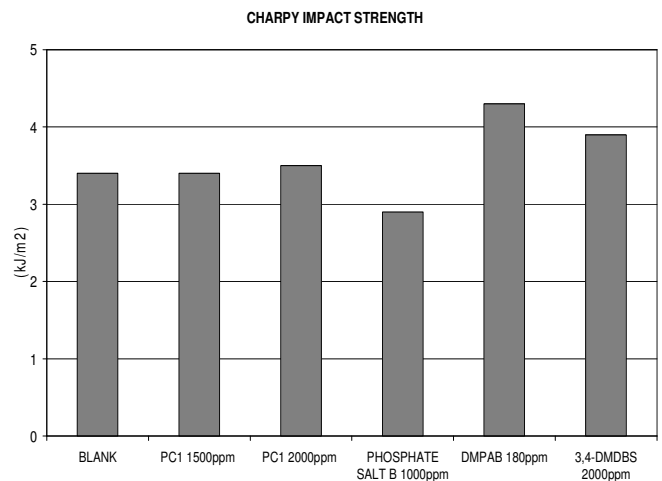


Figure 16. Charpy IS at RT notched in homo PP

Another important characteristic associated with the high stiffness-clarity balance that PC1 offers is its superior heat resistance. The HDT performance of PC1 was reflected in **Figure 15**. It is important to note that the heat resistance improved with increasing concentration of PC1. 1500ppm and 2000ppm of PC1 recorded higher values than the un-nucleated sample, DMPAB and 3,4-DMDBS, with 2000ppm of PC1 showing a similar performance to the PHOSPHATE SALT B.

For a successful clarifier like PC1 it is vital that the impact-stiffness balance is high. **Figure 16** showed that the Charpy impact strength values for PC1 at 1500ppm and 2000ppm were higher than that of the PHOSPHATE SALT B and slightly lower than the values obtained for DMPAB and 3,4-DMDBS.

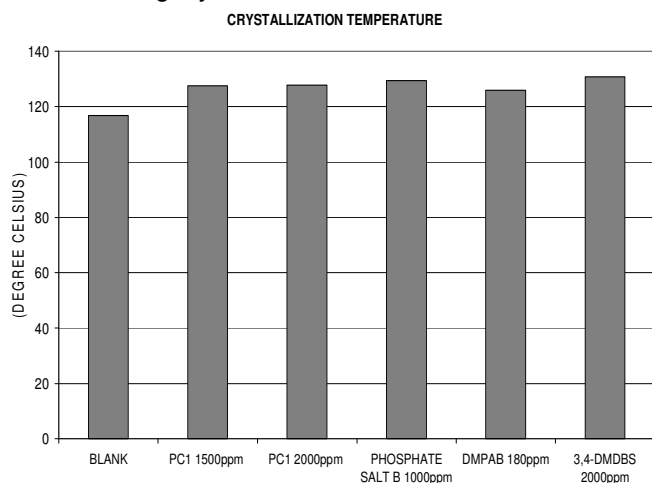


Figure 17. Crystallization temperature in homopolymer PP

Figure 17 illustrated how PC1 increased the crystallization temperature when added to homopolymer PP.

These results demonstrate that PC1 is also an excellent clarifier for homopolymer PP with a high impact-stiffness balance that can also achieve much improved heat resistance.

RIKACLEAR PC1 AS A CLARIFIER IN CONTROLLED RHEOLOGY GRADES (HOMOPOLYMER PP)

The control of the molecular weight distribution of polypropylene resins by peroxide degradation (vis-breaking process) is widely used in the polymer industry. It allows one to adjust the viscosity of these resins to the level required for processing applications. The purpose of this work was to characterize the influence of peroxide degradation on the optical and mechanical properties of a PP homopolymer.

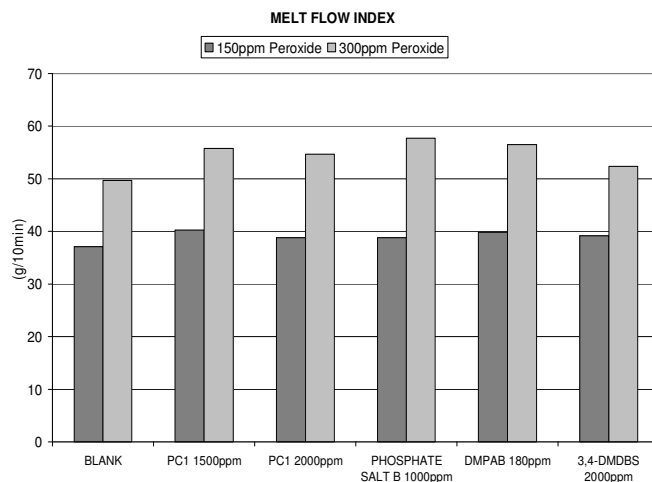


Figure 18. Melt flow rate when adding 150ppm & 300ppm of Trigonox 101

Figure 18 showed the increase on the melt flow rate when 150ppm and 300ppm of peroxide were added to the formulation, leading to materials with MFR of 40g/10min and 55g/10min respectively.

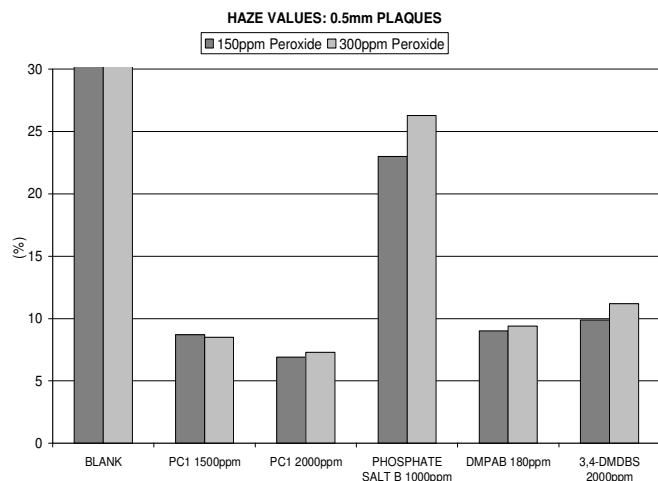


Figure 19. Haze value for 0.5mm plaques in HOMO-CRG

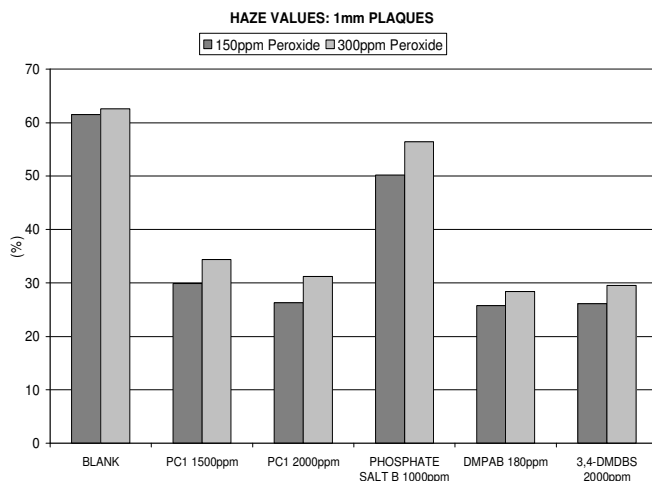


Figure 20. Haze value for 1mm plaques in HOMO-CRG

Even for homopolymer PP it is essential to achieve a high level of clarity in the presence of peroxide. RiKACLEAR PC1 exhibited the best performance for CRG in terms of haze for 0.5mm injection moulded plaques when compared to the blank resin, 3,4-DMDBS, PHOSPHATE SALT B and DMPAB (**Figure 19**). PC1 at 1500ppm showed no variations in the haze values when adding between 150ppm and 300ppm of peroxide. At 2000ppm of PC1, the haze was still the lowest, whereas for PHOSPHATE SALT B and 3,4-DMDBS the results increased by 2%. In the case of 1mm plaques (**Figure 20**), the haze results for PC1 were comparable to that of 3,4-DMDBS and DMPAB, and were still much lower than that of PHOSPHATE SALT B.

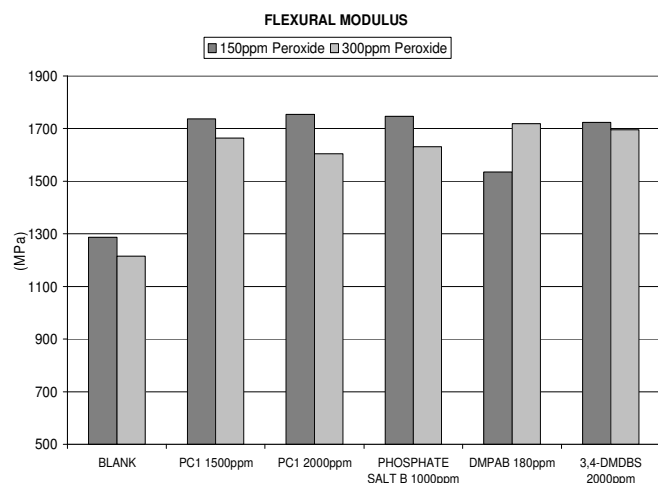


Figure 21. Flexural modulus in HOMO-CRG

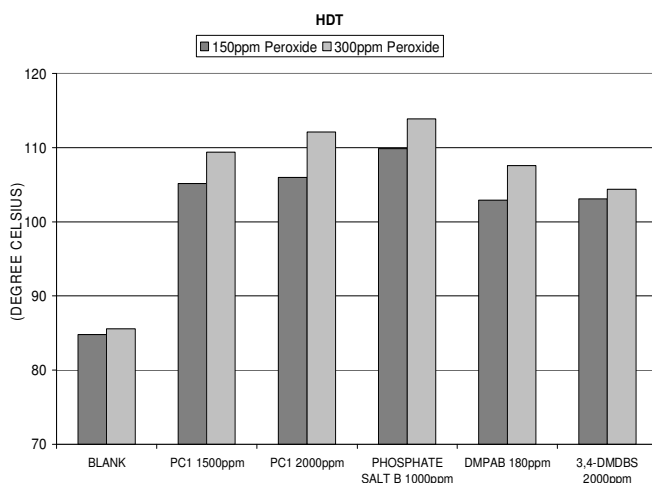


Figure 22. HDT in HOMO-CRG

As seen in the PP random copolymer controlled rheology grades, the addition of peroxide in the formulation could lead to a significant decrease in the stiffness of the material. **Figure 21** showed a slight drop in stiffness for all nucleated samples, except for DMPAB, when addition levels of peroxide went from 150ppm to 300ppm.

Concerning the heat resistance, an increase of the HDT values was observed for all nucleated materials when 300ppm of peroxide was added to the formulation, and it is noticeable that both PC1 samples presented higher HDT values compared with DMPAB and 3,4-DMDBS.



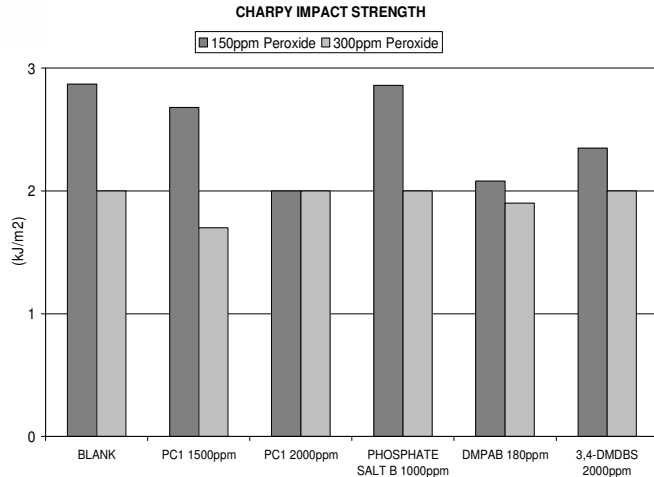


Figure 23. Charpy IS in HOMO-CRG

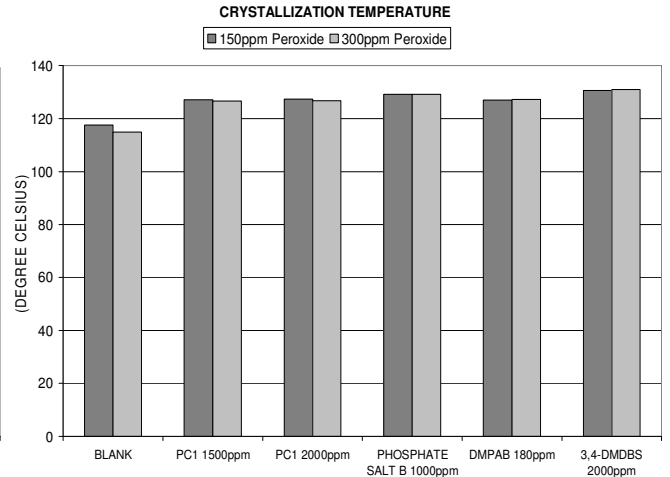


Figure 24. Crystallization temperature in HOMO-CRG

In the presence of peroxide, the loss of impact strength for PC1 at 1500ppm was minimal when compared to the blank material and the PHOSPHATE SALT B, whereas DMPAB and 3,4-DMDBS showed a large decrease of the impact strength when compared to the unnuclated sample. For PC1 at 2000ppm, the loss of impact was similar to that of DMPAB and 3,4-DMDBS when 150ppm of peroxide was added to the formulation, but with a concentration of 300ppm of peroxide, there was no loss in impact strength when in comparison with the unnuclated sample.

No sign of degradation was observed in the crystallization temperature shown in **Figure 24**, with PC1 maintaining a high Tc regardless the amount of peroxide added.

Once again, the results shown above confirm that the performance of RiKACLEAR PC1 is not affected in controlled rheology grades.

RIKACLEAR PC1 AS A NUCLEATOR IN POLYPROPYLENE BLOCK COPOLYMER

Impact copolymers are physical mixtures of homopolymer and random copolymer, with the overall mixture having ethylene contents of 6-15%. Block copolymer are used when enhanced impact resistance is needed, especially at freezer temperature and below. The random copolymer part of the mixture, due to its high ethylene content (45-65%), is termed the rubber phase. As the rubber content of the mixture is increased, so is the impact resistance, but at the expense of the stiffness of the material [4]. Therefore, it is particularly important to obtain a material with much improved stiffness in order to achieve an impact-stiffness balance.

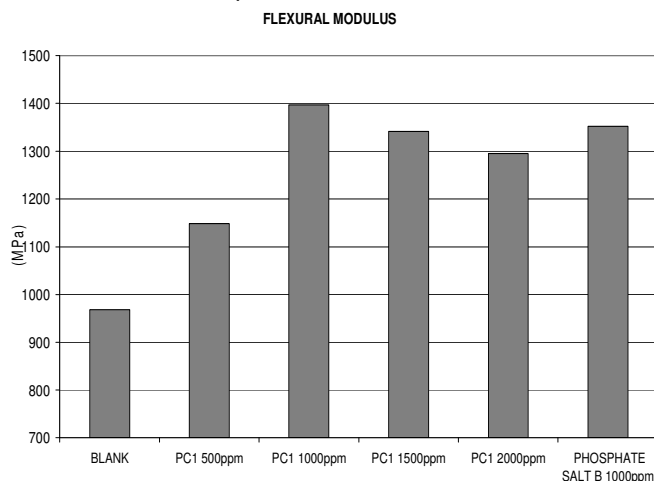


Figure 25. Flexural modulus in block copolymer

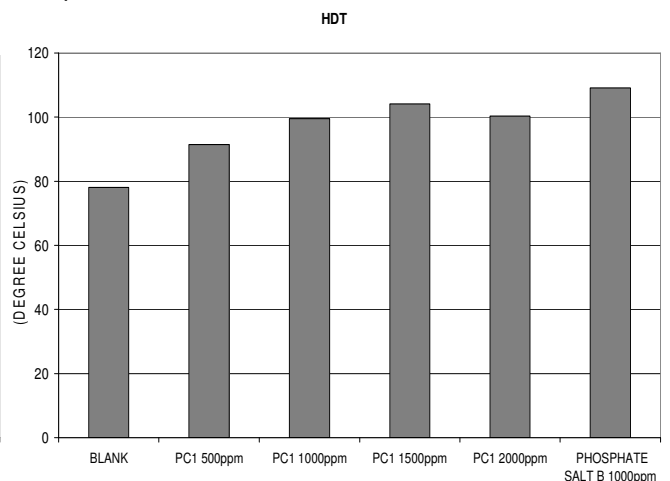


Figure 26. HDT in block copolymer

Figure 25 showed that PC1 significantly increased the stiffness of the material compared to the blank sample. In addition, PC1 containing material achieved a similar or even superior performance to that containing the PHOSPHATE SALT B (from a concentration of 1000ppm of PC1).

Associated with this excellent stiffness, PC1 also exhibited superior heat resistance in block copolymer when compared to the blank material (**Figure 26**).

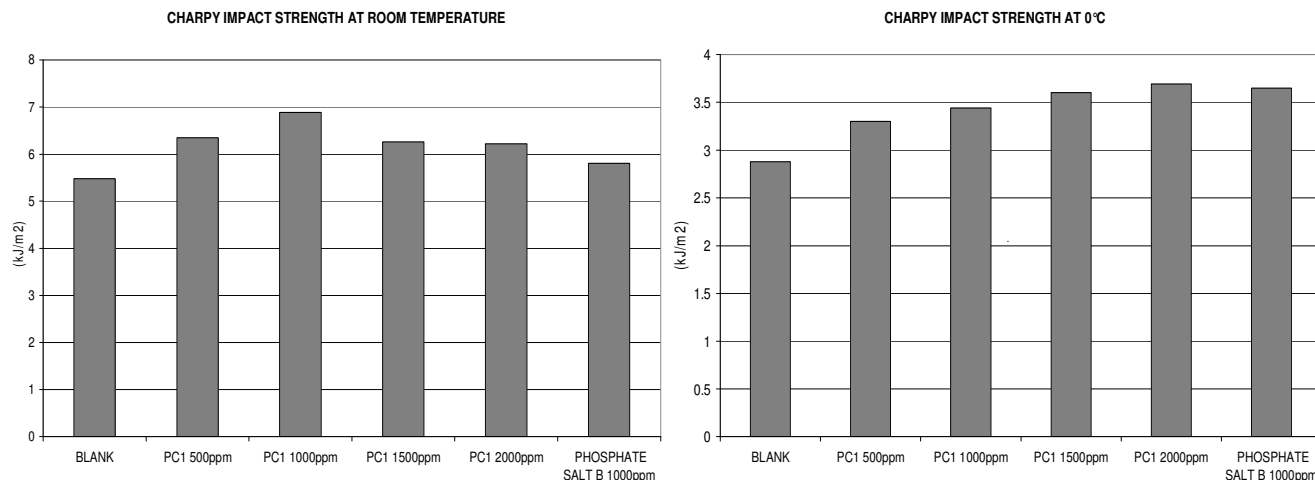


Figure 27. Charpy IS at RT notched in block PP **Figure 28. Charpy impact strength at 0°C notched in block PP**

Two of the most important industries in which impact copolymers are widely used are the automotive and packing applications industries, where the excellent impact strength, especially at temperatures below freezing point, is a much sought property.

Impact copolymers were characterised by high impact strength as can be observed in **Figure 27**. Charpy impact strength values were improved in the presence of RiKACLEAR PC1 for all addition levels when compared to the blank sample and PHOSPHATE SALT B.

Moreover, the increase in impact strength provided by PC1 when the test was carried out at 0°C (**Figure 28**) was quite remarkable. It is important to note that all PC1 concentrations improved the impact strength compared to the blank material and from a concentration of 1500ppm of PC1 the results were comparable to that of the PHOSPHATE SALT B.

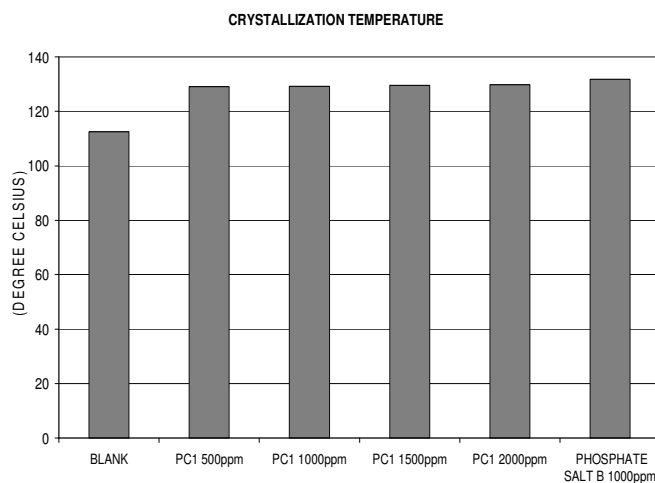


Figure 29. Crystallization temperature in block copolymer

Figure 29 featured the increase in crystallization temperature provided by PC1 in block copolymer.

Therefore, the experiments showed that in addition to being an excellent clarifier with superior stiffness in clear applications, RiKACLEAR PC1 can provide excellent stiffness in non-clear applications and superior impact strength even at zero degrees temperatures.

RiKACLEAR PC1 AS A NUCLEATOR IN CONTROLLED RHEOLOGY GRADES (BLOCK PP)

Controlled rheology grades of polypropylene extend and improve the characteristics of PP. High MFR PP are mostly produced by vis-breaking process, when a peroxide is added to the formulation before the extrusion. The purpose of this work was to characterize the influence of peroxide degradation on the mechanical properties of a PP impact copolymer.

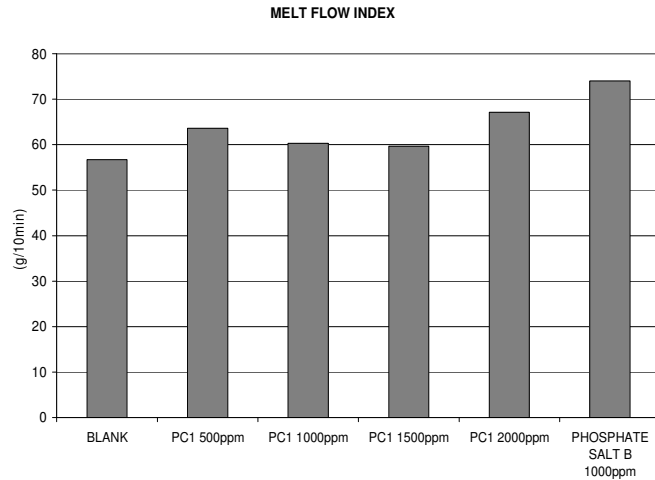


Figure 30. Melt flow rate when adding 100ppm of Trigonox 101

Figure 30 showed the increase on the melt flow rate when 100ppm of peroxide was added to the formulation, leading to materials with MFR of ca. 60g/10min.

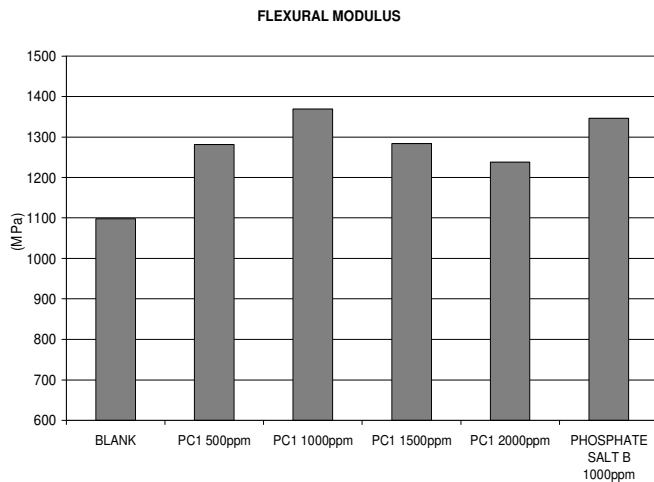


Figure 31. Flexural modulus in BLOCK-CRG

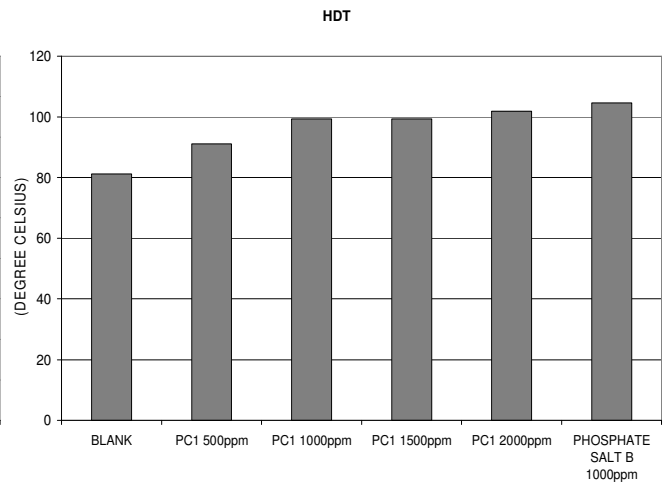


Figure 32. HDT in BLOCK-CRG

Figure 31 showed that the addition of PC1 significantly increased the stiffness of the material compared to the blank sample, even in the presence of peroxide. PC1 samples achieved a similar or even superior performance to that containing PHOSPHATE SALT B.

Associated with this excellent stiffness, RiKACLEAR PC1 also gave superior heat resistance in CRG block copolymer when compared to the blank material (**Figure 32**), and similar results as the PHOSPHATE SALT B from a concentration of PC1 of 1000ppm.

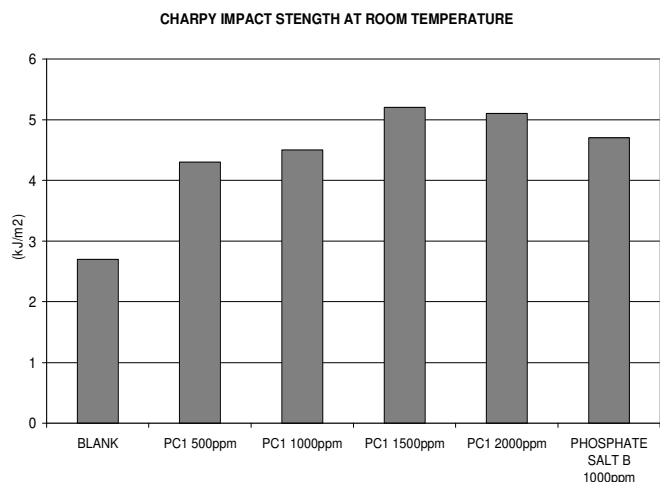


Figure 33. Charpy IS at RT in BLOCK-CRG

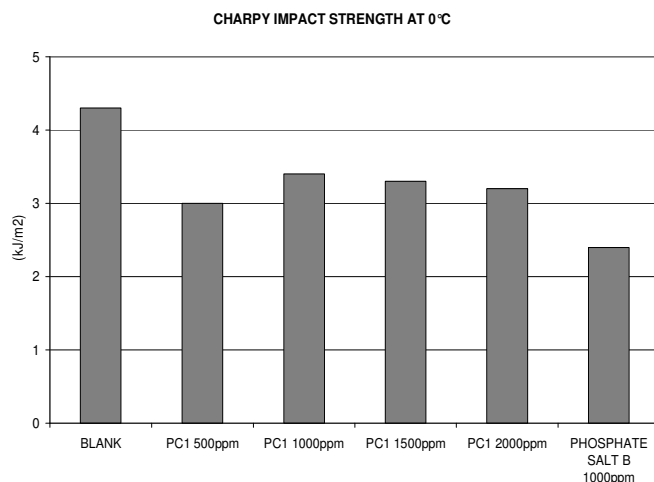


Figure 34. Charpy IS at 0°C in BLOCK-CRG

Figure 33 presented Charpy impact strength values that were improved in the presence of RiKACLEAR PC1 for all addition levels when compared to the blank sample. Results similar or even superior to that of the PHOSPHATE SALT B were obtained from a concentration of PC1 of 1000ppm.

Moreover, the increase in stiffness provided by PC1 did not sacrifice the impact strength of the material as it can be seen in **Figure 33 & 34**. When the Charpy impact test was carried out at 0°C, it is important to notice that the loss in impact performance at 0°C for all PC1 concentrations was minimal when compared to the performance of the PHOSPHATE SALT B.

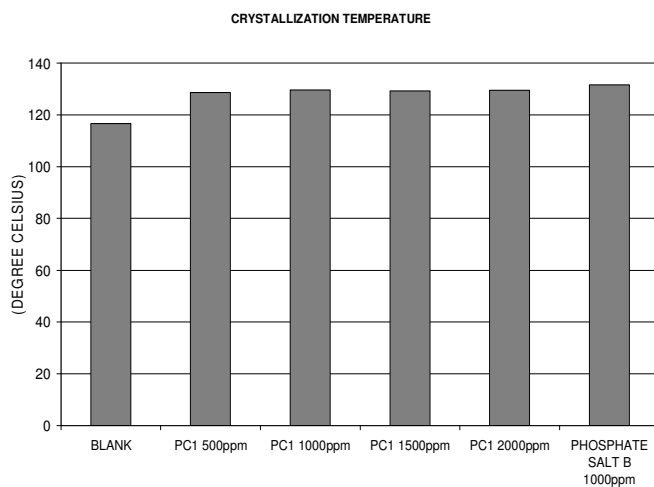


Figure 35. Crystallization temperature in BLOCK-CRG

Figure 35 illustrated how PC1 increased the crystallization temperature when added to PP impact copolymer.

Therefore, the inclusion of RiKACLEAR PC1 in controlled rheology grades shows no signs of degradation in the mechanical properties of the material: PC1 can provide excellent stiffness in non-clear applications and superior impact strength even at zero degrees temperatures.



CONCLUSIONS

RiKA International Limited presents its innovative product to the polypropylene industry, **RIKACLEAR PC1**. For the first time, a non-acetal sorbitol product has become the new benchmark in clarified polypropylene: PC1 offers very low haze values and an exceptional stiffness-impact balance in random copolymer, homopolymer, including controlled rheology grades. Since RIKACLEAR PC1 is based on a new chemistry, it confers excellent organoleptic properties for clarified polypropylene. Moreover, long-term aging tests have shown that RIKACLEAR PC1 offered the lowest haze values and the highest gloss results for 0.5mm and 1mm injection moulded plaques in random copolymer [5]. Another study was also carried out to assess the stability of PC1 by regrinding it in a multiple pass extrusion process and measuring the haze of 1mm plaques. Compared to the traditional clarifiers and nucleators, RiKACLEAR PC1 exhibited consistently lower haze values with increasing number of passes (up to five pass extrusion steps) [5]. All these features make RIKACLEAR PC1 the best and the most stable clarifier in the market.

In addition, owing to superior stiffness, heat resistance and impact strength achieved at room and zero degrees temperatures, RIKACLEAR PC1 is also a highly effective nucleator in non-clear applications, even in controlled rheology grades.

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