RECENT DEVELOPMENTS IN NUCLEATION OF POLYPROPYLENE

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BIOGRAPHICAL NOTE

Estibaliz Santamaria graduated from the University of the Basque Country in Spain in 1998 after spending one year as Erasmus student at the Manchester Metropolitan University (UK) studying commercial photoinitiators for UV curable systems in collaboration with Prof. N.S. Allen.

She then obtained a Masters Degree which included a dissertation on the mode of action of various antistatic agents in collaboration with Repsol-YPF.

Estibaliz was awarded her doctorate at the Manchester Metropolitan University (UK) for the study of the mechanism of a novel polymer stabilizer in PVC, a project in collaboration with Akcros Chemicals.

She joined RiKA International in 2003 where she is engaged in the research and product development of clarifiers and nucleators for polypropylene. To date she has been involved in several patent applications in the field of clarifiers for polypropylene.

Recently married, she resides in Manchester, England.

ABSTRACT

RiKA International Limited presents an update on their three newest clarifiers/nucleators for polypropylene. These three innovative products are as follows: (1) **RiKAFAST**, with its free aldehyde suppression technology, is an effective clarifier with extremely low organoleptic properties. (2) For the first time, a non-acetal sorbitol product namely **RiKACLEAR PC1** has become the new benchmark in clarified polypropylene. Haze values in random copolymer are extremely low and the stiffness-impact balance is vastly improved at very low addition levels. Based on new technology, this new product has no taste and odour issues. This new chemical is also an extremely effective nucleator in non-clear applications. Data presented demonstrates that when RiKACLEAR PC1 in block polypropylene, high stiffness values are achieved, as well as high impact strength at both ambient and zero degrees temperatures. Moreover, an aging study carried out showed that RiKACLEAR PC1 is the best long-term clarifier in the market even in controlled rheology grades. (3) **NJ Star NU-100** crystalline type and content can be controlled by processing conditions which can lead to excellent i.e., impact strength or stiffness with superior impact-stiffness balance.

1. RiKAFAST

RiKA International Limited is offering the polypropylene industry a new concept in clarifiers –**RIKAFAST**. This product has been developed at RiKA's state-of-the-art technology centre in Manchester (England) and at New Japan Chemical Company's R&D centre in Kyoto (Japan).

It is widely known that all acetal sorbitol nucleators have a tendency to exude free aldehyde into the PP resin which can cause taste and odour problems. New Japan Chemical Co Ltd (NJC) and RiKA International Limited have developed a process that not only minimises the emission of free aldehyde during production, but also produces a more stable acetal sorbitol molecule that releases minimal aldehyde during processing and moulding.

Independent testing has shown that RiKAFAST offers a superior performance in terms of haze (Figure 1), free aldehyde emission (Figure 2) and for the first time in the market, taste and odour, comparable to 3,4-DMDBS (Figure 3). Typical free aldehyde levels in moulded polypropylene resin nucleated with RiKAFAST are 50% lower than 3, 4-DMDBS.

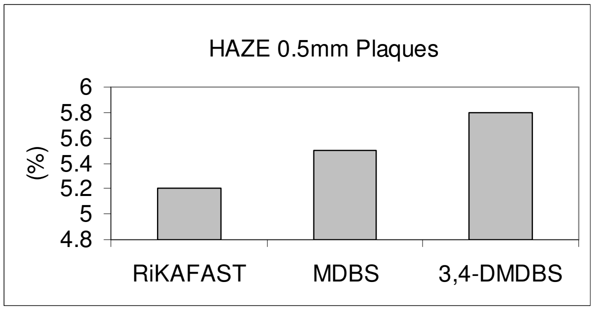


Figure 1. Haze measurements in 0.5mm Plaques

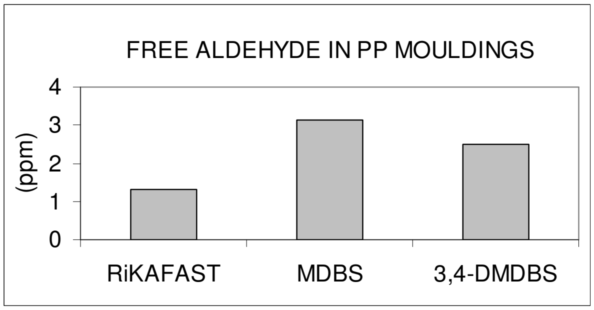


Figure 2. Free aldehyde in PP mouldings

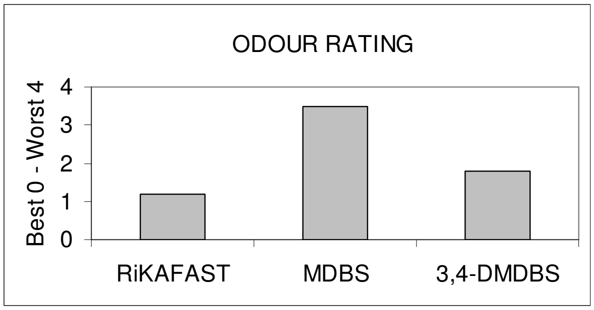


Figure 3. Odour rating Best to Worst (0-4)

Plant tests have shown that RiKAFAST works equally well in homopolymer, random copolymers and controlled rheology grades. Working closely with leading polypropylene companies, NJC & RiKA have answered their quest for an effective clarifier that has no taste and odour issues.

2. RiKACLEAR PC1

RiKACLEAR PC1, a newly developed clarifying agent, is the first non-sorbitol based clarifier that meets all of the polypropylene industries' requirements: transparency, stiffness, impact strength, heat resistance and organoleptics. 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.

During development, RiKACLEAR PC1 was given the designation Perfect Chemical (PC) by the R&D staff at NJC, as it was their intention to design the perfect chemical as a clarifier/nucleator for polypropylene. The main goals of the development project were high clarity, high stiffness, high impact strength, high heat resistance and no taste and odour. 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.

RiKACLEAR PC1 AS A CLARIFIER IN POLYPROPYLENE RANDOM COPOLYMER

Polypropylene is a semi-crystalline material that as the molten polymer cools down, the polymer chains begin to form crystals at foreign particles in the melt[1]. In random copolymer, due to the presence of ethylene monomer in the polypropylene chain as a defect in the chain regularity, the melting temperature of the resin is a relatively low value of 145℃. The ethylene content present inhibits the crystallization of the chain, giving way to lower melting and less perfect crystals. Moreover, since the size of the crystals is quite small (generally lower than the wavelength of visible light) high levels of clarity can be achieved.

As can be clearly seen from Figure 4, PC1 significantly reduced the haze levels in 0.5mm plaques at 1500 and 2000ppm, compared to 3,4-DMDBS and a commercial phosphate salt. 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 levels for PC1 were slightly higher than that of 3,4-DMDBS.

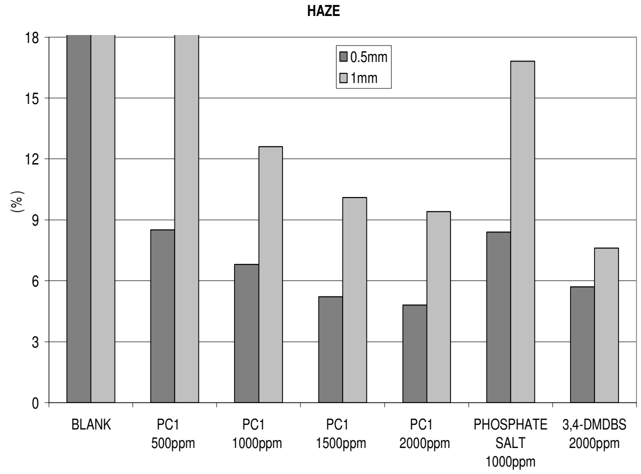


Figure 4. Haze measurements in random copolymer

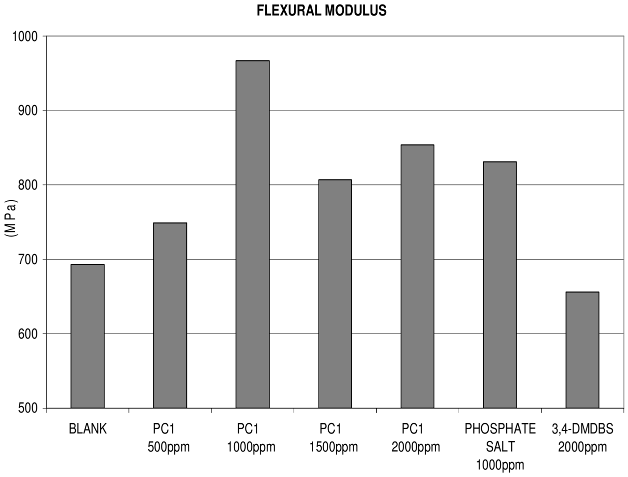


Figure 5. Flexural modulus in random copolymer

An important feature of PC1 along with its clarifying properties is the higher stiffness that confers to the material. Figure 5 is an excellent example of what can be achieved using PC1 in random copolymer. All addition levels showed a significant improvement compared to 3,4-DMDBS, and 1500 and 2000ppm exhibited a similar or better performance than that of the phosphate salt. Consequently, PC1 can improve not only the transparency, but also the stiffness of the material.

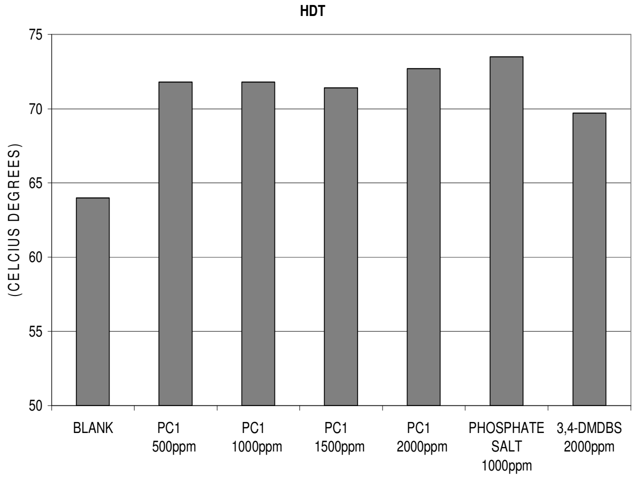


Figure 6. Heat Distortion Temperature in RACO

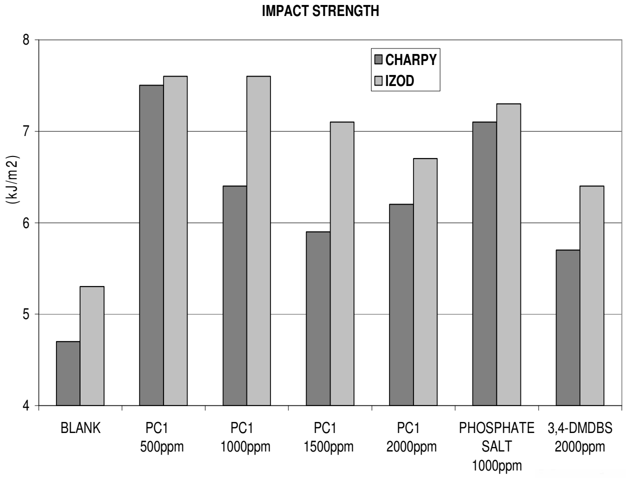


Figure 7. Impact strength at RT in RACO-notched.

Furthermore, the high stiffness that PC1 evidenced was also counterbalanced with a high heat resistance (Figure 6). All HDT values of PC1 were higher than that of 3,4-DMDBS and similar to the phosphate salt.
In addition, Figure 7 demonstrates that there was no loss in impact strength associated with the high stiffness and heat resistance conferred by PC1 to the material. All impact strength values for PC1, both Charpy and Izod, were superior to those of 3,4-DMDBS, with similar Izod values obtained for the phosphate salt containing material. Charpy values were, however, lower compared to that of the phosphate salt.

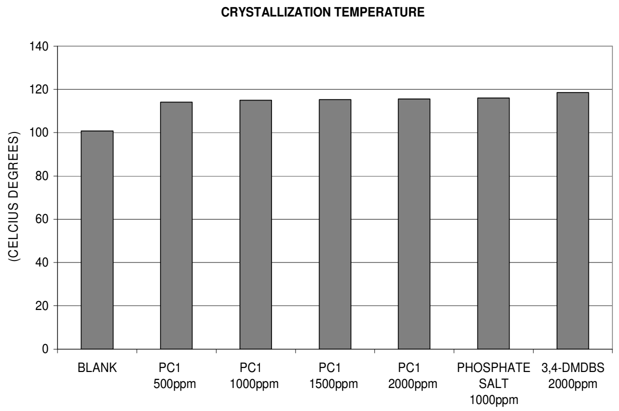


Figure 8. Crystallization temperature in random copolymer

The crystallization of PP from the melt can be improved with the addition of foreign nuclei to the polymer melt. In Figure 8 PC1 reflected a high increase in the Tc which proved that, in addition to providing a reduction in the moulding cycle time, PC1 is as excellent clarifier with superior mechanical properties and with no taste and odour issues.

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

Controlled rheology PP is produced by degrading normal PP to give a product with a high melt flow rate (MFR), lower molecular weight (MW), narrower molecular weight distribution (MWD) and hence easier and more consistent flow. Peroxide addition is most widely used and these are added prior to extrusion and pelletizing. When peroxide and a PP polymer mixture are heated the peroxide will produce free radicals that react with the PP molecules. The peroxide attacks randomly but 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 of a well-known commercial peroxide were added to formulations containing different concentrations of PC1. The optical and mechanical properties of the material were then assessed.

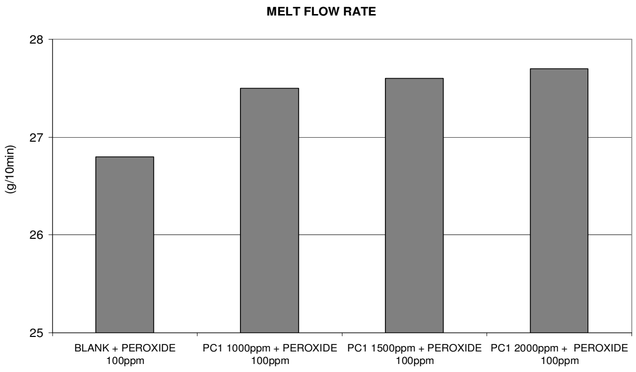
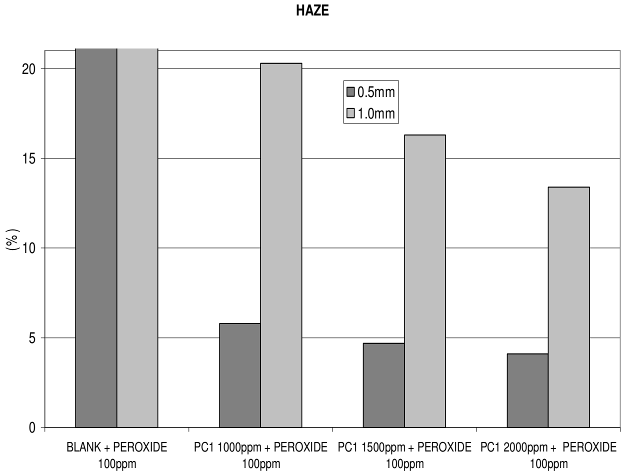


Figure 9. Melt flow rate when adding 100ppm of peroxide

Figure 9 shows the increase on melt flow rate when the peroxide was added to the formulation leading to a material with a MFR of 27g/10min.



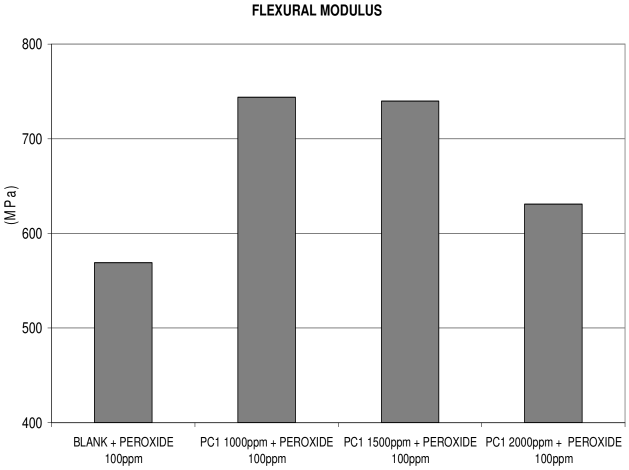
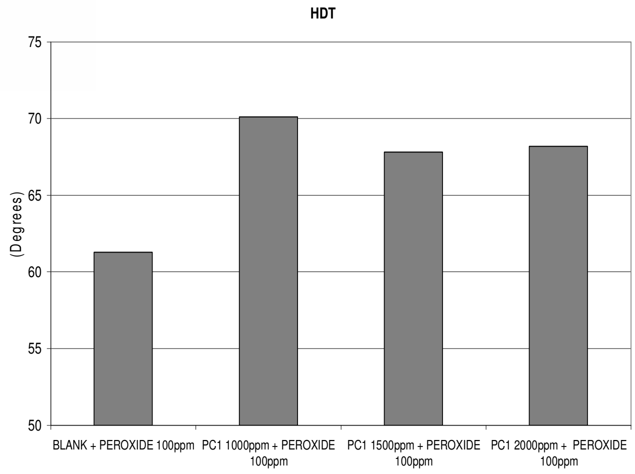


Figure 10. Haze in CRG

Figure 11. Flexural modulus 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 0.5 and 1mm plaques was measured when the peroxide was added and the results shown in Figure 10. For 0.5mm thickness plaques, low haze values were maintained, which ruled out any degradation of PC1 and at 1mm plaques thickness, the haze increased slightly, but still within acceptable limits.

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 11 shows that lower concentration levels of PC1 led to higher stiffness values in the presence of the peroxide. However, no substantial signs of degradation were observed.



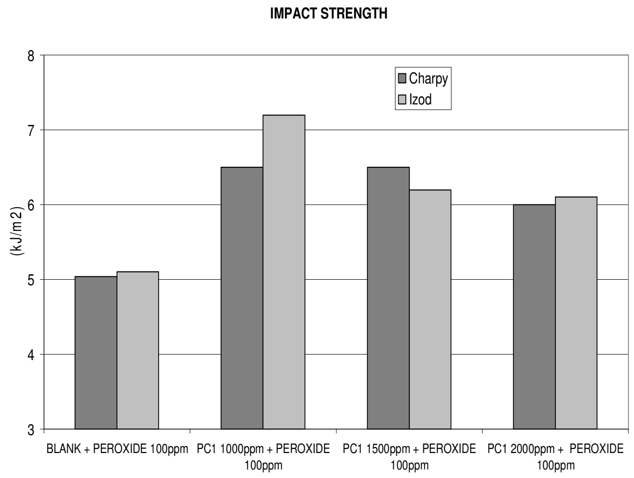


Figure 12. HDT in CRG

Figure 13. Impact strength at RT –notched in CRG

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 12 demonstrated that no major degradation took place on addition of the peroxide to PC1 containing samples.

Equally important in controlled rheology grades is to maintain the impact-stiffness balance of the material. The impact strength values for both Charpy and Izod reported in Figure 13 showed that this equilibrium was retained and no loss of impact strength was recorded on addition of the peroxide.

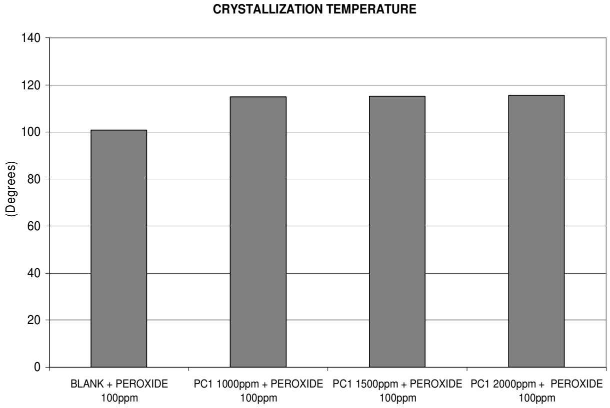


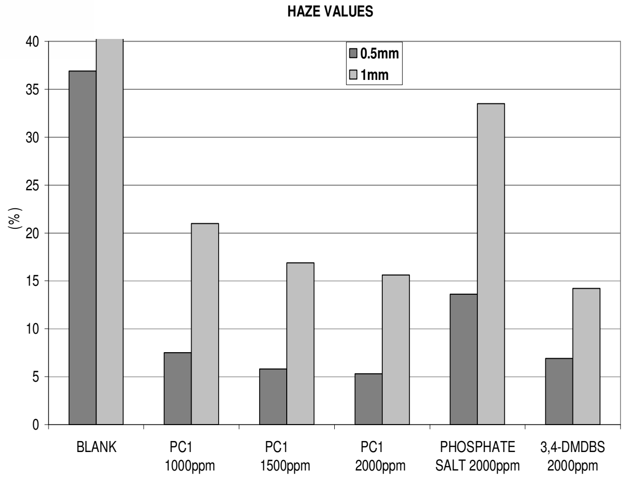
Figure 14. Crystallization temperature in CRG

No sign of degradation was observed either in the crystallization temperatures recorded in Figure 14, with PC1 providing a significant increase in the Tc in the presence of the peroxide. 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 and does not affect the organoleptics of the finished article.

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.



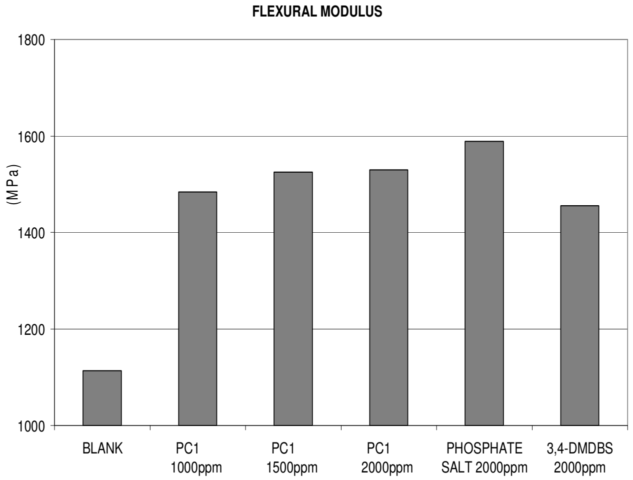


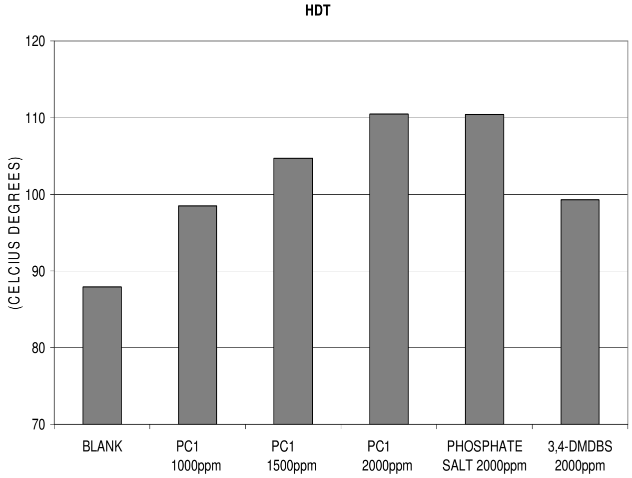
Figure 15. Haze in homopolymer PP

Figure 16. Flexural modulus in homopolymer PP

To assess the effect on the clarity of PC1 in homopolymer PP, plaques of 0.5 and 1mm thickness were injection moulded and their haze measured (Figure 15). All PC1 addition levels reduced the haze in the material compared to that of 3,4-DMDBS and the phosphate salt in 0.5mm plaques. Moreover, at half the concentration of 3,4-DMDBS, PC1 at 1000ppm showed a similar haze improvement. In the case of 1mm plaques, PC1 at 2000ppm exhibited a similar performance to that of 3,4-DMDBS.

As mentioned before, one of the most important features of PC1 is the high stiffness associated with this excellent clarifier. In Figure 16 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 and 3,4-DMDBS, including a higher rigidity value for the PC1 concentration at half of the addition level of 3,4-DMDBS. However, the stiffness provided by the phosphate salt was slightly higher than that of PC1 at any given concentration.

These results confirm again that, PC1 perfectly balances transparency and stiffness compared to 3,4-DMDBS and the phosphate salt.



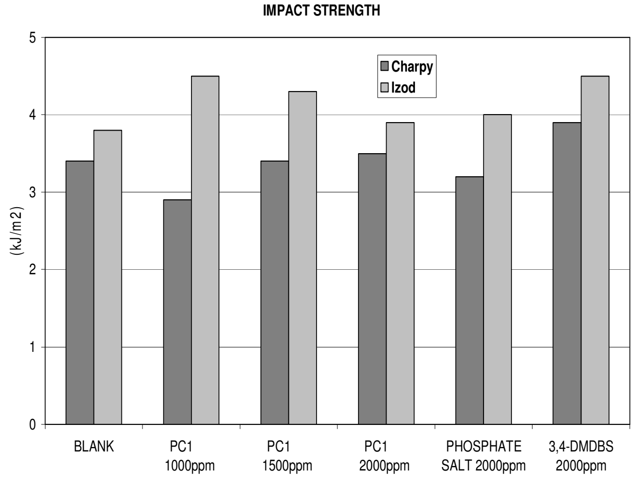


Figure 17. HDT in homopolymer PP

Figure 18. Impact strength 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 17. It is important to note that PC1 at 1000ppm achieved a similar HDT value to that of 3,4-DMDBS at 2000ppm. 1500 and 2000ppm of PC1 recorded higher values than 3,4-DMDBS, with 2000ppm of PC1 showing a similar performance to the phosphate salt.

For a successful clarifier like PC1 it is vital that the impact-stiffness balance is high. Figure 18 shows that the Charpy impact strength for PC1 at 1500 and 2000ppm was higher than that of the phosphate salt and slightly lower than the value obtained for 3,4-DMDBS. Moreover, at 1000ppm PC1 achieved a similar impact performance at half the concentration of the phosphate salt. In the case of the Izod impact strength, low concentration levels of PC1 exhibited higher impact values than that of the phosphate salt and also similar values to that of 3,4-DMDBS. At 2000ppm, the Izod impact was similar to that of the phosphate salt and slightly lower than 3,4-DMDBS.

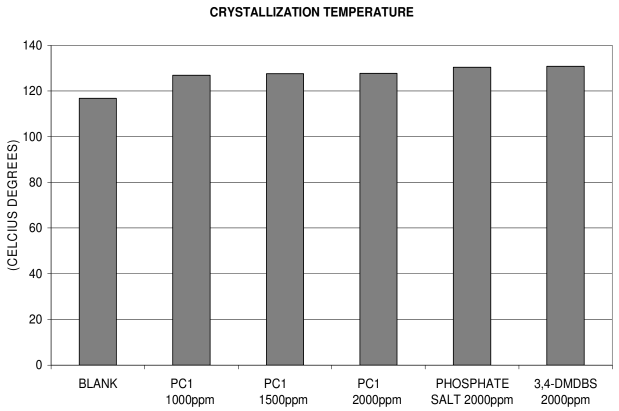


Figure 19. Crystallization temperature in homopolymer PP

Figure 19 illustrates how PC1 increased the crystallization temperature when added to homopolymer PP.

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

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%. The random 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 too is the impact resistance, but at the expense of the reduction of the stiffness of the material[3].

The impact strength in this type of copolymers is not only a function of the rubber content, but also of its size, shape and distribution. Therefore, it is of the outmost importance to obtain a material with much improved stiffness in order to achieve an impact-stiffness balance.

Two of the most important industries where 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.

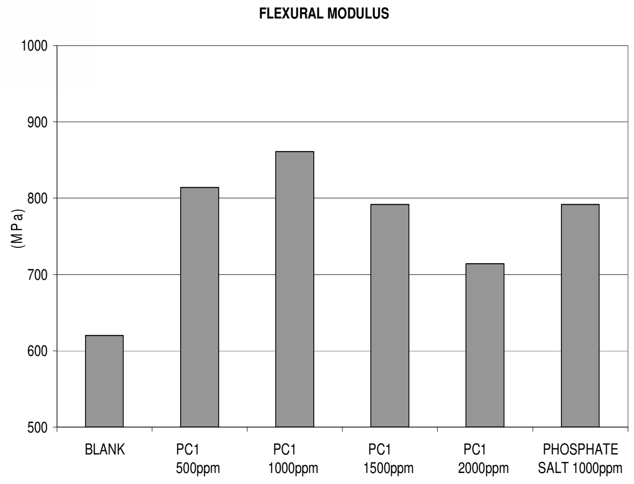


Figure 20. Flexural modulus in block copolymer

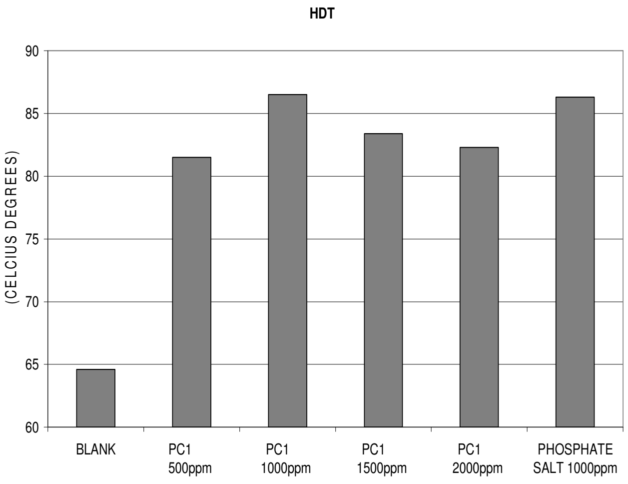


Figure 21. HDT in block copolymer

Figure 20 shows that PC1 significantly increased the stiffness of the material compared to the blank, especially at concentrations up to 1500ppm. In addition, PC1 containing material achieved a similar or even superior performance to that containing the phosphate salt. Associated with this excellent stiffness, PC1 also exhibited superior heat resistance in block copolymer when compared to the blank and the phosphate salt (Figure 21).

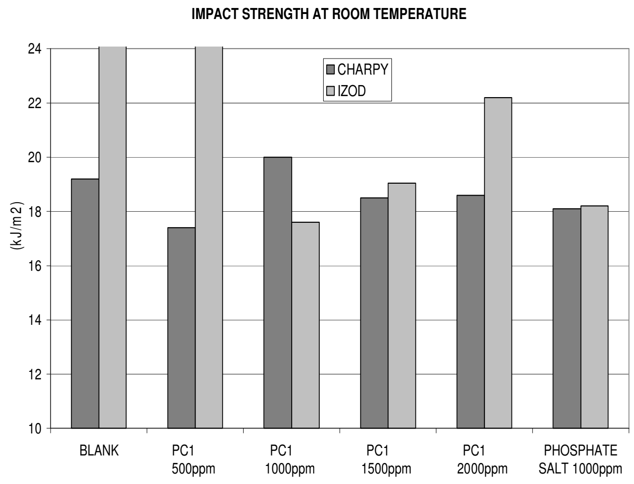


Figure 22. Impact strength at RT notched in block PP

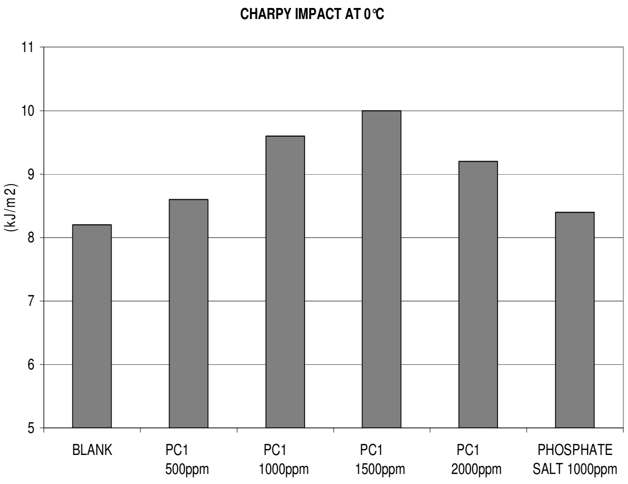


Figure 23. Charpy impact strength at 0°C notched in block PP

As pointed out before, impact copolymers are characterised by high impact strength as can be observed in Figure 22. Both Charpy and Izod impact strength values were high and hardly any improvement was observed upon the addition of PC1 or the phosphate salt at any concentration level.

Nevertheless, the increase in impact strength provided by PC1 when the testing was carried out at 0°C was quite remarkable. It is important to note that all PC1 concentrations highly improved the impact strength compared to the blank and to the phosphate salt, with PC1 at 1500ppm achieving a notable 25% increase.

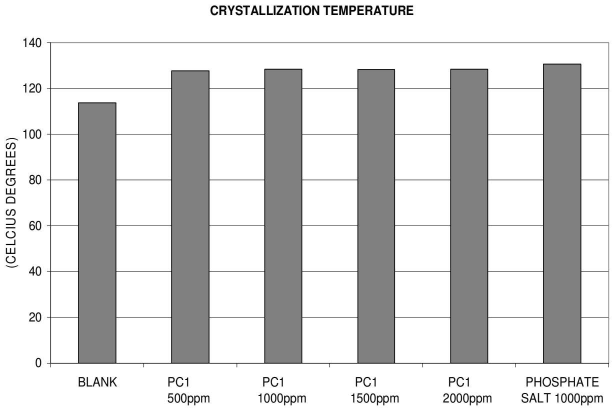


Figure 24. Crystallization temperature in block copolymer

Figure 24 features 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.

PC1 AS A LONG-TERM CLARIFIER COMPARED TO 3,4-DMDBS

A well-known feature of the sorbitol based clarifiers is that owing to their sugar-based chemical structure, they appear to suffer from thermal decomposition, leading to a phenomenon called plate out, where a white residue appears in the surface of the mould during the injection process. As a result, running times are shortened and costly delays in production, due to the cleaning process, arise.

To assess the compatibility of PC1 with the resin and its long-term stability, the haze and gloss of two different formulations containing PC1 at two different concentrations in a low ethylene content PP resin were compared against 3,4-DMDBS. The haze and gloss of 0.5 and 1mm thickness plaques were measured over a one month period.

Figure 25 shows clearly how the haze in 0.5mm plaques increased considerably overtime for 3,4-DMDBS compared with PC1 at any given concentration. Similarly, the gloss also decreased significantly overtime in the case of 3,4-DMDBS, compared with PC1 (Figure 26). This fact confirms, on one hand, the long-term stability of PC1 as clarifier and on the other hand, its superior long-term performance when compared with 3,4-DMDBS.

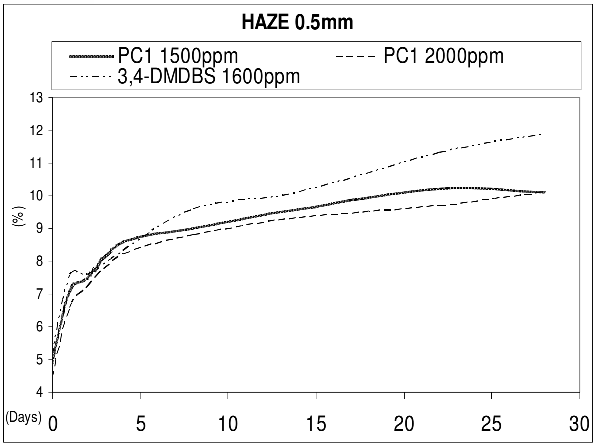


Figure 25. Long-term Haze 0.5mm plaques

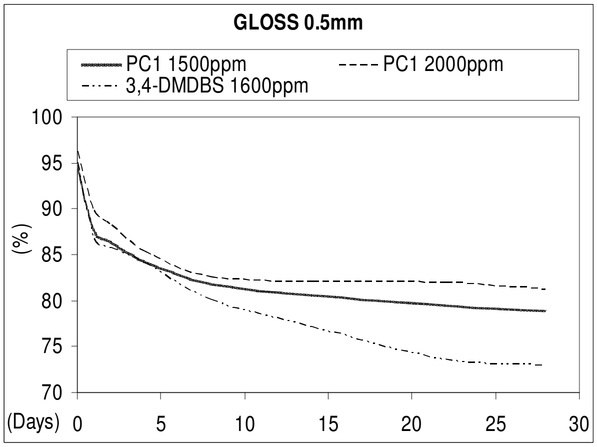


Figure 26. Long-term Gloss 0.5mm plaques

A similar trend was observed when the haze and gloss were measured in 1.0mm plaques thickness (Figures 27 and 28). It was especially interesting the dramatic loss of gloss of around 20% (Figure 28) of 3,4-DMDBS after just one week compared to PC1.

The long-term stability of PC1 and 3,4-DMDBS was also assessed in the presence of peroxide, for controlled rheology grades. Figures 29 to 32 confirm again that even in this case, PC1 is an excellent long-term clarifier which shows a superior performance compared to 3,4-DMDBS.

This feature, in addition to the excellent balance between transparency and mechanical properties such as stiffness, heat resistance and impact strength compared to the common commercial nucleating agents and clarifiers, make PC1 the new benchmark for the polypropylene industry.

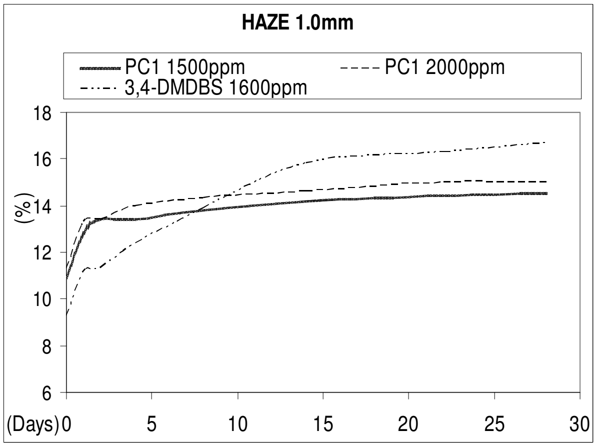


Figure 27. Long-term Haze 1.0mm plaques

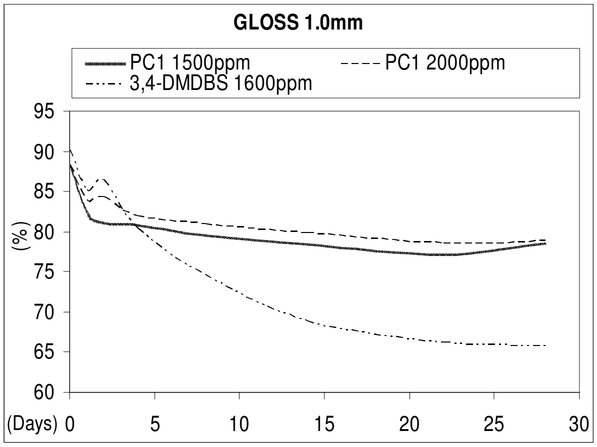


Figure 28. Long-term Gloss 1.0mm plaques

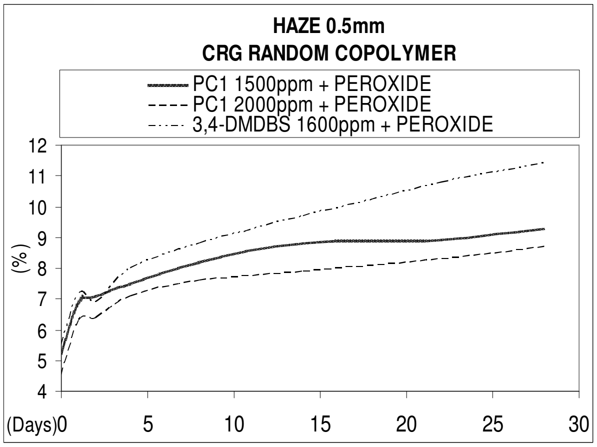


Figure 29. Long-term Haze 0.5mm plaques in CRG

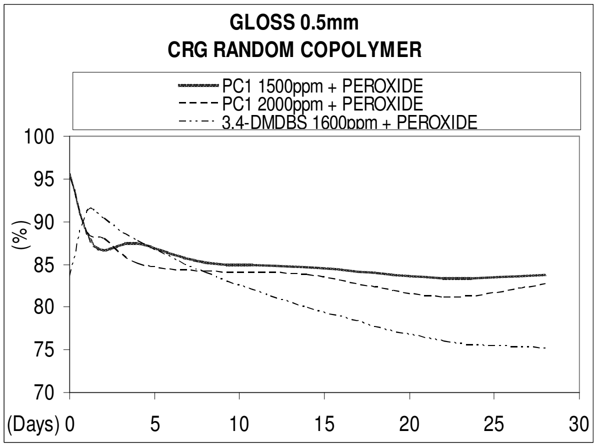


Figure 30. Long-term Gloss 0.5mm plaques in CRG

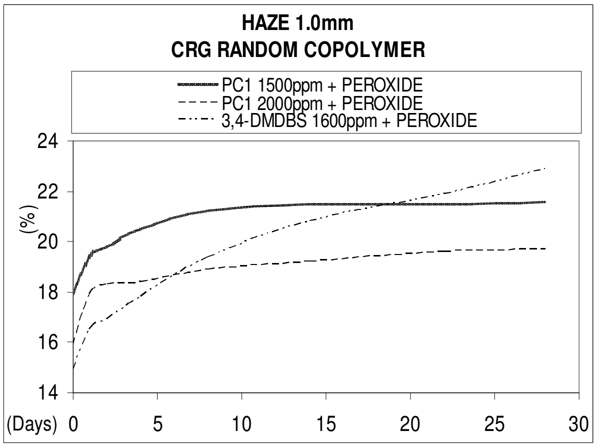


Figure 31. Long-term Haze 1.0mm plaques in CRG

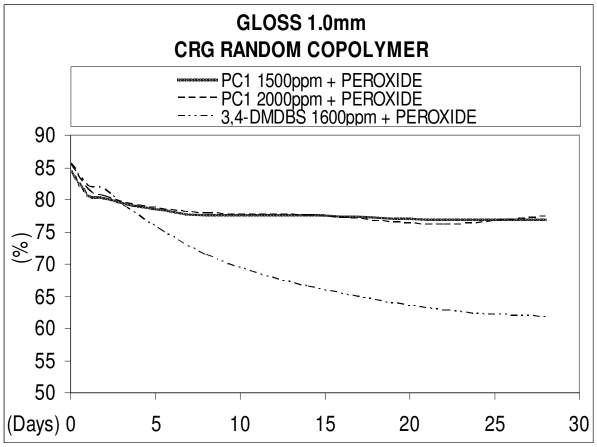


Figure 32. Long-term Gloss 1.0mm plaques in CRG

3. NJ Star NU-100

Isotactic polypropylene (iPP) is a semi-crystalline polymorphic material that can crystallize in four different forms: monoclinic (*α*-phase), hexagonal (*β*-phase), orthorhombic (*γ*-phase), and smectic phase[3]. The most common form of crystal is the *α* form, which is thermodynamically stable and is predominant under common processing conditions The *β* form, however, is more difficult to form as a higher energy level is required to reach that energy state, making it unstable and further processing, can result in the formation of the alpha form. It has been traditionally generated by introducing a coloured pigment or a nucleating agent. The *β*-crystals have a melting point around 12-13℃ lower than that of the *α*-crystals. An important feature of this *β* form is that when annealed or under shear stress[4] it undergoes a physical transformation into α-crystals and simultaneous to this conversion is the developing of voids or microvoids which ultimately reduce the density of the material.

NJ Star NU-100 was first introduced by New Japan Chemical Co Ltd in the early 1990's. It was the first non pigmenting *β*-nucleator that effectively induced the crystallization of iPP. Like all β-nucleators, achieving a balance between the high impact strength and high stiffness is a combination of factors which include the beta crystals as well as the type and shape of the crystalline form.

New Japan Chemical Co Ltd has intensely researched into the optimum conditions to produce two different preparations which can be designed to achieve specific properties in the material, properties that are controlled by unique processing conditions and crystallographic forms.

Data presented here refer to injection moulding results, which show the effect of NJ Star NU-100, in two different preparation forms A and B, in homo (h-PP) and impact copolymers (b-PP). Preparation A is a formulation designed to produce a material with excellent impact strength, while maintaining an impact-stiffness balance. Preparation B, however, is designed to achieve a high stiffness material with no loss of impact strength.

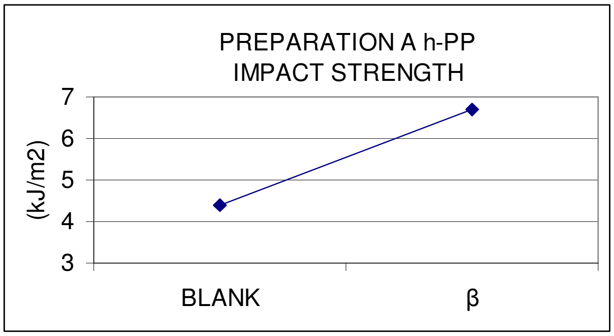


Figure 33. Impact strength Prep.A at RT notched

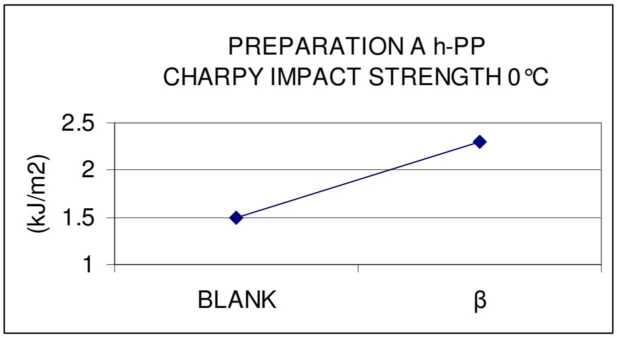


Figure 34. Charpy impact strength at 0°C notched

Figure 33 shows that on addition of Preparation A to a homopolymer PP there was more than a 50% increase in impact strength when compared to the blank resin. An increase in Charpy impact strength was also observed when the testing was carried out at 0°C (Figure 34). These results are extremely important for instance, in pipe applications, where high impact strength is required.

In terms of flexural modulus, Figure 35 shows that Preparation A significantly increased the stiffness of the material. Furthermore, Preparation A exhibited high Heat Distortion Temperature (HDT) values on addition to homopolymer when compared against the blank resin (Figure 36).

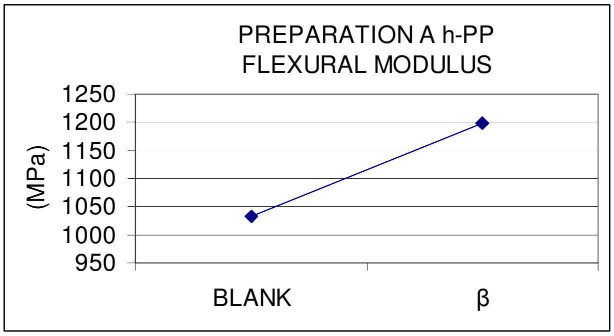


Figure 35. Flexural modulus for Preparation A of NU-100

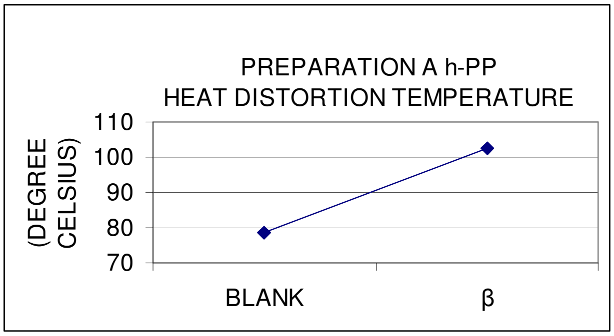


Figure 36. HDT for Preparation A of NU-100

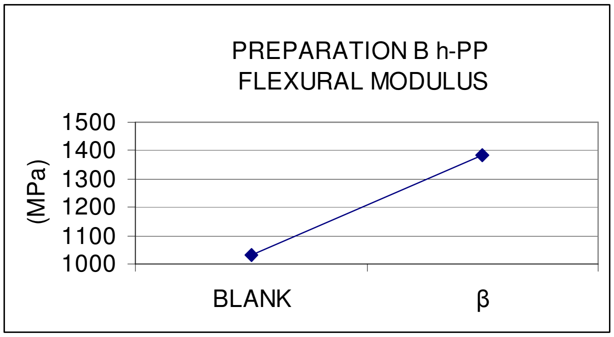


Figure 37. Flexural modulus for Preparation B of NU-100

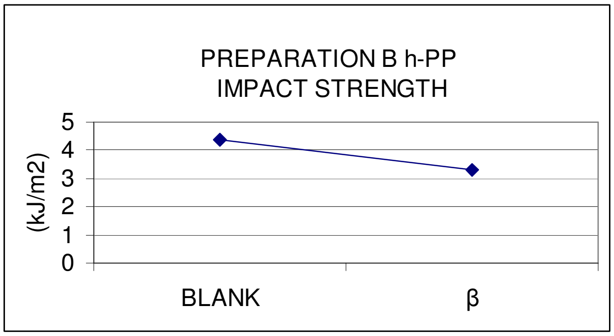


Figure 38. Impact strength Prep. B at RT notched

In homopolymer, Figure 37 shows that Preparation B can achieve a significant increase in flexural modulus, with a minimal reduction in the impact strength (Figure 38). However, an increase in the Charpy impact strength was observed at 0°C (Figure 39). The HDT results for Preparation B (Figure 40) reflected an even more spectacular increase when compared against the blank (45°C increase). These results clearly suggest the potential end-use applications of NU-100, for example, in hot water pipe applications, where HDT values well above 100°C would overcome problems such as softening of the material.

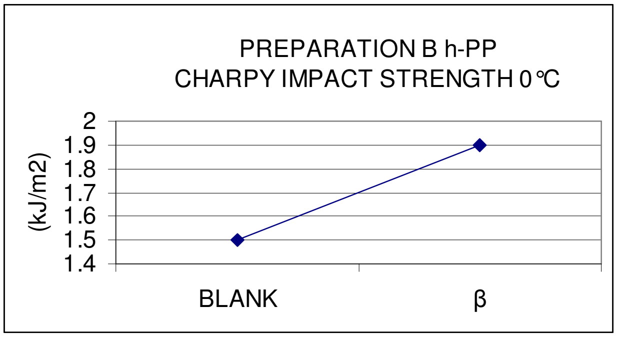


Figure 39. Charpy impact strength at 0°C notched

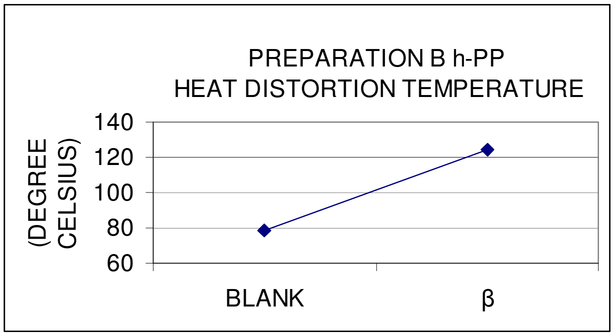


Figure 40. HDT for Preparation B of NU-100

In the case of the performance of NU-100 in block copolymer, Figure 41 shows a remarkable near three-fold increase in impact strength for Preparation A when compared with the un-nucleated resin. An increase of about 33% was also observed for the Charpy impact strength at 0°C (Figure 42).

Associated with these impact strength values are also the high HDT values obtained when compared to the blank (Figure 43) and no loss of stiffness was observed against the un-nucleated resin (Figure 44).

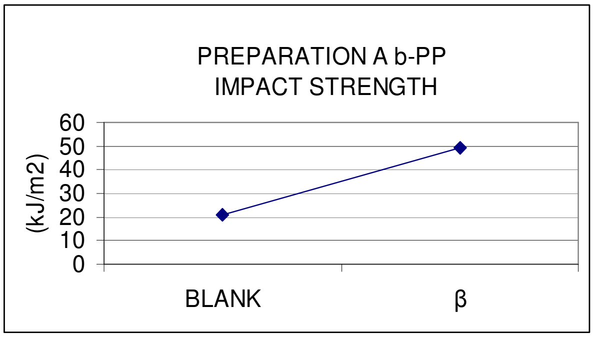


Figure 41. Impact strength for Preparation A

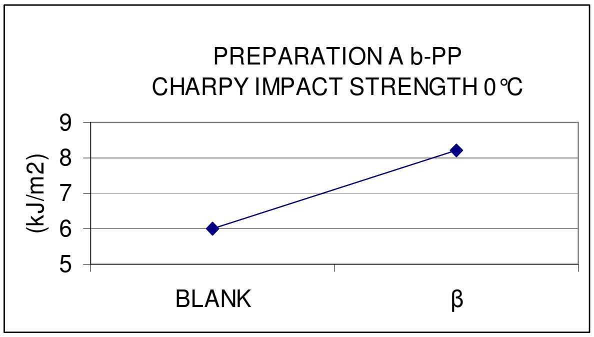


Figure 42. Charpy impact strength at 0°C notched

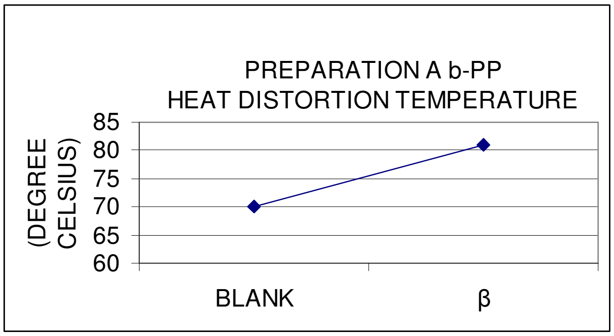


Figure 43. HDT for Preparation A of NU-100

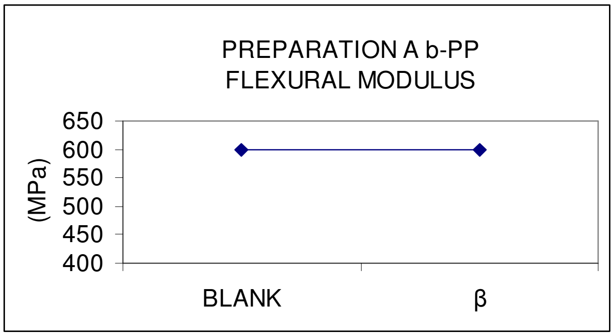


Figure 44. Flexural modulus for Preparation A

The impact strength of Preparation B in Figure 45 shows again a massive near three-fold increase when the resin was β-nucleated with NU-100, against the un-nucleated material. Also, about a 40% increase in Charpy impact strength was observed at 0℃ (Figure 46). With a view to assessing if the impact-stiffness equilibrium was maintained, Figure 47 shows the high stiffness values obtained for Preparation B in block copolymer. Moreover, Figure 48 shows that HDT values for Preparation B were 50% higher than the blank resin.

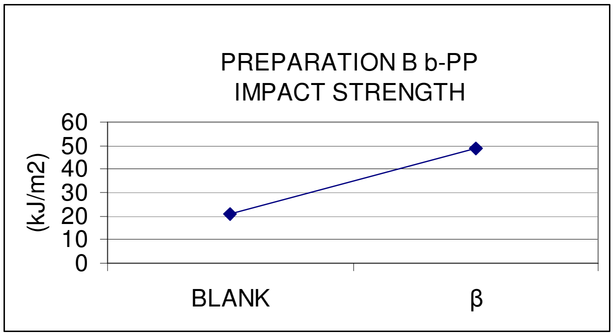


Figure 45. Impact strength for Preparation B

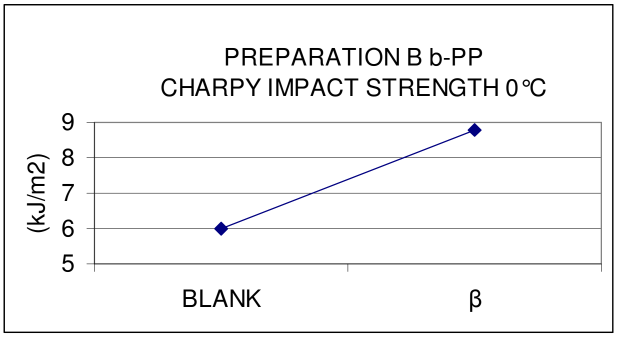


Figure 46. Charpy impact strength at 0°C notched

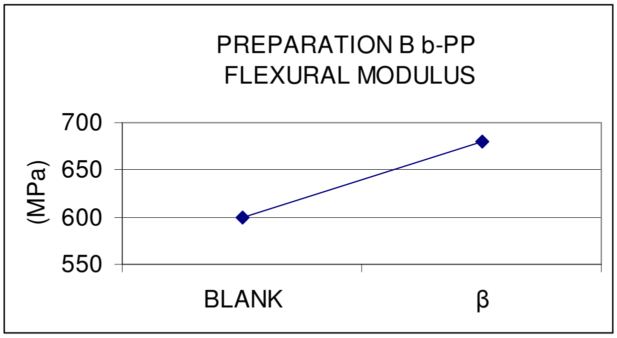


Figure 47. Flexural modulus for Preparation B

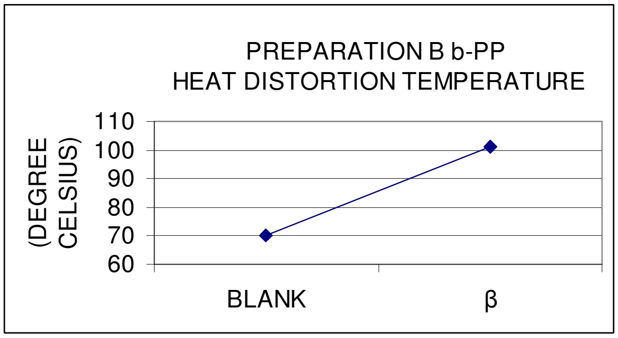


Figure 48. HDT for Preparation B

CONCLUSIONS

RiKA International Limited presents three innovative products to the polypropylene industry:

(1) **RiKAFAST**, an effective clarifier with extremely low organoleptic properties.

(2) **RiKACLEAR PC1,** the new benchmark in clarified polypropylene: a non-acetal sorbitol product with low haze values and a high stiffness-impact balance with no taste and odour issues. In addition, owing to high stiffness and impact strength achieved at room and zero degrees temperatures, it is considered a highly effective nucleator in non-clear applications. Moreover, an aging study carried out showed that RiKACLEAR PC1 is the best long-term clarifier in the market even in controlled rheology grades.

(3) **NJ Star NU-100**, which can be successfully designed to produce two different types of materials according to the properties required i.e., impact strength or stiffness with an excellent impact-stiffness balance.

EXPERIMENTAL

MATERIALS

All formulations contained a standard base stabilization system.

A low ethylene content random polypropylene with MFR 13g/10min was used in the evaluation of RiKAFAST.In the case of PC1, a polypropylene random copolymer of MFR 10g/10min and ethylene content of 3.9wt% was used. In the aging study, a low ethylene content random copolymer with a MFR of 12g/10min was used.

The polypropylene homopolymer used in the evaluation of PC1 was of MFR of 12g/10min, and the resin used in the NU-100 study was a resin of MFR 8g/10min. A polypropylene block copolymer of MFR 18g/10min and ethylene content of 11wt% was used for both PC1 and NU-100 evaluations.

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 the RiKAFAST and PC1 evaluations the extrusion temperature was held at 250°C. Similarly, the injection moulding was performed at a melt temperature of 230°C and a mould temperature of 20°C.

MEASUREMENTS

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.

The aging study was carried out on the 0.5mm and 1.0mm injection moulded plaques at 80°C.

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

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