BREAKING BARRIERS TO HIGHER OUTPUT RATES WITH DENSIFIED ULTRAFINE TALC DURING MELT COMPOUNDING ON THE COROTATING INTERMESHING TWIN SCREW EXTRUDER

Joseph A. Radosta, Specialty Minerals Inc.
Edward Beecher, Krupp Werner & Pfleiderer Corp.

Abstract

The melt compounding of densified and nondensified ultrafine talc into polypropylene was performed on a 40 mm corotating twin screw extruder for comparison of compounding characteristics and product performance properties. Compounding nondensified talc was found to be volume limited by the maximum quantity of talc that the machine could be fed whereas the densified talc compounding was torque limited. The plastic performance properties for both types of talc filled compounds were comparable and would be widely acceptable for these high performance grades of talc filled polypropylene. Predictions of throughput rates on larger machines with higher toque ratings are included.

Introduction

Fine and ultrafine size talcs are highly effective, low cost reinforcements for a variety of thermoplastics, from inexpensive polypropylene and thermoplastic polyolefins (TPOs) to top-of-the-line engineering thermoplastics and alloys. The combination of high aspect ratio and fine particle size for premium talc grades give unique mechanical property balances to a talc reinforced polymer, enhancing both stiffness and impact.

Polyolefins have particularly benefited by the incorporation of these premium, cost effective talc products were commodity polyolefin grades have been converted into engineering compounds that are used in high performance automotive and appliance applications. As an example, talc reinforced TPO automotive applications are experiencing high growth and include both interior (e.g. dashboard) and exterior (e.g. bumper) parts. Many papers have been written, demonstrating the unique property advantages and expanded market opportunities that are now possible when formulating with combinations of ultrafine talc, polypropylene (either conventional or high modulus homopolymer grades), and impact modifiers (EPR or m-Plastomer).[1,2,3]

The one remaining area of concern for fine and ultrafine talcs has now been resolved; namely their inherent low powder densities. Low density, fine talcs have occasionally contributed to processing difficulties during melt compounding at commercial production speeds. Using a specialized densification process, fine and ultrafine densified talc grades have been developed for filled polymer applications that overcome processing concerns while still maintaining excellent plastics performance properties.[4] Among the many advantages offered by these new densified grades are:

- Increased throughput rates
- Shipping economics
- Easier handling
- Reduced dusting
- Higher talc loadings

This paper presents the results of a commercial scale twin-screw extrusion compounding trial conducted at Krupp Werner & Pfleiderer. The primary objective of the trial was to obtain real world comparisons of maximum compounding rates and compounding product quality for densified versus non-densified ultrafine talc when incorporated at 20% and 40% loading levels in polypropylene copolymer.

Experimental

Materials

The polypropylene copolymer used in this study was a commercially available medium impact grade having a melt flow rate of 4.

The two ultrafine talcs (nondensified and densified) evaluated here were commercially available products selected from a family of appearance and high heat stable grades of reinforcing talc. The ultrafine talc products have a unique combination of very fine particle size distribution and high aspect ratio platelets. Top and average particle sizes (as determined by a sedigraph unit) are given in Table 1 along with a comparison of bulk and tap powder densities. Note that the densification process gives a bulk density increase of 500% and a tap density increase of greater than 300%.

Melt Compounding Equipment

Polypropylene pellets were metered by a loss-in-weight belt feeder. The talc was fed to two locations by individual loss-in-weight feeders.

The ZSK 40 twin screw extruder (TSE) was configured with eleven barrels (Figure 1). The first barrel was an open barrel for the polymer and a portion of the filler. This was followed by a plugged open barrel which could have served as an alternate feed location. Barrel 3 was a closed barrel. Barrel 4 was an open barrel fitted with a vent insert for upstream venting of the talc feed in barrel 5, a combi barrel with the top vent plugged. The talc was transported to barrel 5 with a 40 mm twin screw sidefeeder. The compounding section was in barrels 6 though 9. These were solid barrels except for barrel 8, which was a plugged open barrel which could have been reconfigured for downstream venting of the compounding section. Barrel nine was an open barrel fitted with a vent insert and a vacuum dome for vacuum venting. The product was pressurized in barrel 10, a closed barrel and stranded using a 45^{o} discharge die with a six hole, 4.0 mm diameter die plate.

Other equipment used during the trial included a water ring vacuum pump for the vacuum vent, a water bath for strand cooling, an air knife to dry the strands, and a strand cutter.

Screw Designs

Two screw designs were tested in this trial (Figures 2 and 3). Their melting, filler feeding, and venting sections were the same. The principle difference was their compounding sections. The first screw design (which was configured to be the stronger compounding screw set) consisted of two 1.5 L/D forward pitch kneading blocks followed by a 1.5 L/D conveying section. The majority of the compounding was then performed by a section of seven three lobe eccentric kneading blocks followed by a reverse pitch kneading block. The second screw design (moderately strong) reversed the compounding configuration with six three lobe eccentric kneading blocks followed a conveying element and then two 1.5 L/D forward pitch kneading blocks and a reverse pitch kneading block.

Specimen Fabrication and Testing for Product Quality

All 20% and 40% ultrafine talc filled compounds, obtained from the Krupp Werner & Pfleiderer trial, were then fabricated into ASTM test specimens on an 84-ton Arburg screw injection molding machine (at a melt temperature of 190°C). Product quality tests were subsequently performed on the test specimens to give the following plastic performance properties:

- 23°C DYNATUP Falling Weight Impact
- Notched Izod Impact (ASTM D-256)
- Flexural Modulus (ASTM D-790)

Results and Discussion

There are many successive barriers to higher output rates that need to be overcome when incorporating fine minerals into thermoplastics on a compounding twin screw extruder. As illustrated in Figure 4, some of the more critical barriers are:

- VOLUME LIMITATIONS
- EXCESSIVE MELT TEMPERATURE
- EXCESSIVE TORQUE
- REDUCED PRODUCT QUALITY

Maximum output will be achieved at the point where one or more of these barriers can no longer be circumvented. This trial was conducted to compare densified and nondensified ultrafine talc in a real world melt compounding situation when incorporated at 20% and 40% loadings into polypropylene copolymer. Compounding characteristics and product quality were evaluated as throughput rates were increased in steps.

Processing and Quality Performance

The compounding trial results for the 40% nondensified and densified ultrafine talc filled formulations are presented in Tables 2 and 3, respectively. As seen in Table 2, the limit to higher output rates for the nondensified talc was the volumeric capacity of the twin screw extruder at the side feeder port. For either screw set, attempts to go to higher rates above 45 kg/hr (100 lb/hr) would result in backup of talc in the side feeder or increased dusting in the barrel 4 vent on the TSE. However, when using the densified ultrafine talc (Table 3), volume limitations disappeared and the end process limitation to higher output rates became excessive torque. The maximum output rates were 300% higher with the densified talc compared to its nondensified equivalent.

The compounding trial results for the 20% nondensified and densified ultrafine talc filled formulations are presented in Tables 4 and 5, respectively. Again, the limit to higher output rates for the nondensified talc was the volumeric capacity of the twin screw extruder at the side feeder port. For either screw set, attempts to go to higher rates above 90 kg/hr (200 lb/hr) would result in backup of talc in the side feeder or increased dusting in the barrel 4 vent on the TSE. Similarly, when using the densified ultrafine talc (Table 5), volume limitations disappeared and the end process limitation to higher output rates became excessive torque. For the 20% talc formulations, the maximum output rates were 50% higher with the densified talc compared to its nondensified equivalent.

As higher output rates are achieved with the densification process, it is important to evaluate the product quality of the resultant compounds. This is particularly desirable for ultrafine talc formulations, where its exceptional performance in the areas of toughness and reinforcement must be maintained. Tables 6 and 7 summarize the product quality results on compounds obtained from the maximum output runs for 40% and 20% talc formulations, respectively. As seen in the tables, the densified ultrafine talc product gives exceptional performance in toughness and reinforcement that's equivalent to the undensified grade.

Future Prospects for Higher Outputs

These trials were performed on a corotating twin screw extruder with a torque rating of 32.5 Nm per shaft. Higher torque TSE's are now available with up to 30% more torque. Therefore, if the throughput rate continues to be torque limited with the compacted talc, 30% higher throughput rates should be possible. The previous maximum rate of 136 kg/hr (300 lb/hr) could be raised up to 177 kg/hr (390 lb/hr). Another benefit from operating at higher rates and the same screw speed will be a lower discharge temperature.

Thoughput rate expectations on larger machines with the new, higher torque capacity would be as follows:

TSE Diameter (mm)	Rate (kg/hr)
50	345
58	530
70	930

Conclusion

Compounding nondensified talc was found to be volume limited by the maximum quantity of talc that the machine could be fed whereas the densified talc compounding was torque limited. In essence, with densified ultrafine talc we were able to use all of the available power capacity of the corotating intermeshing twin screw extruder, thereby achieving 300% higher output rates at 40% loadings and 50% higher output rates at 20% loadings without compromising plastics performance quality at either loading.

Acknowledgements

The support for this project is provided by Specialty Minerals Inc., a division of Minerals Technologies Inc. and Krupp Werner & Pfleiderer Corp. The authors wish to express appreciation for their encouragement and permission to publish this work.

References

1. Radosta, J. A., "New Ultrafine Talc Expands Market Opportunities for Polyolefins", presented at the Polyolefins VIII RETEC Conference, February 1993.

2. Radosta, J. A., "New Opportunities for Polypropylene Through Combined Use of Ultrafine Talc and Metallocene Produced Impact Modifiers", presented at the International Congress on Metallocene Polymers in Brussels, April 1995.

3. Radosta, J. A., "Recent Advances in Talc as a Modifier for Polyolefins", Presented at the Polyolefins X RETEC Conference, February 1997.

4. Radosta, J. A., "Recent Advances in the Application of Ultrafine Talc for Enhanced TPO Mechanical and Processing Performance:, Presented at the TPOs in Automotive '98 Conference.

Key Words

polypropylene
talc
compounding
densification

Table 1

BULK AND TAP POWDER DENSITIES ARE INCREASED GREATER THAN 3X DUE TO DENSIFICATION PROCESS

	Particle Size		Bulk Density		Tap Density	
	Top Size	Median Size				
	Microns	Microns	grams/cc	(pounds/ft^3)	grams/cc	(pounds/ft^3)
Densified Ultrafine Talc	6μ	0.8μ	0.50	(31)	0.96	(60)
Nondensified Ultrafine Talc	6μ	0.8μ	0.10	(6.4)	0.32	(20)

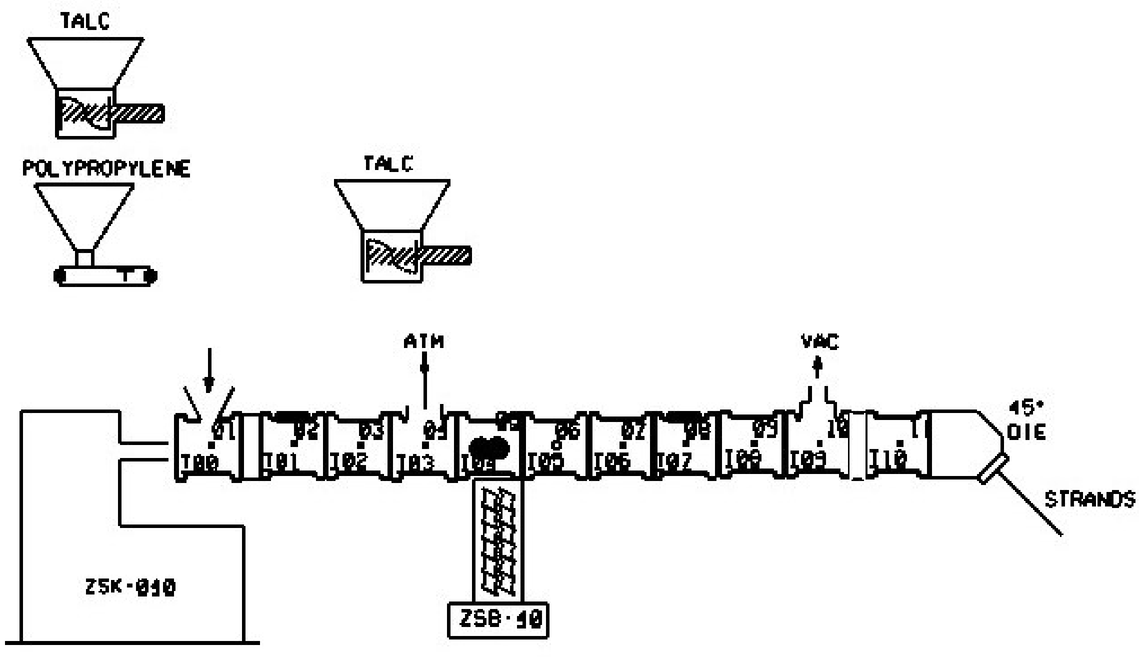

Figure 1. PROCESS FLOW DIAGRAM

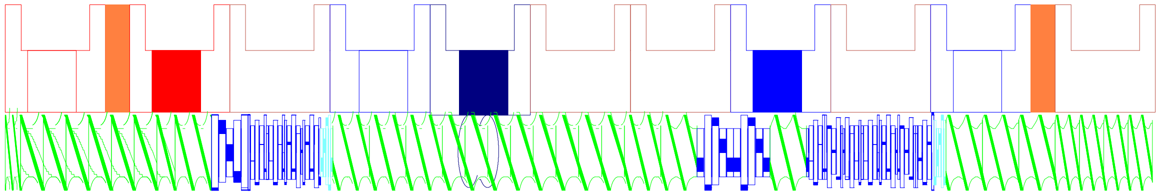

Figure 2. STRONGER SCREW SET

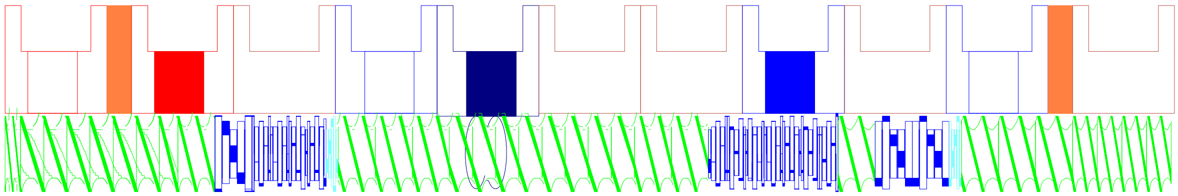

Figure 3. MODERATELY STRONG SCREW SET

Barriers to Higher Output Rates for a Compounding Extruder Producing Filled Polymer Formulations

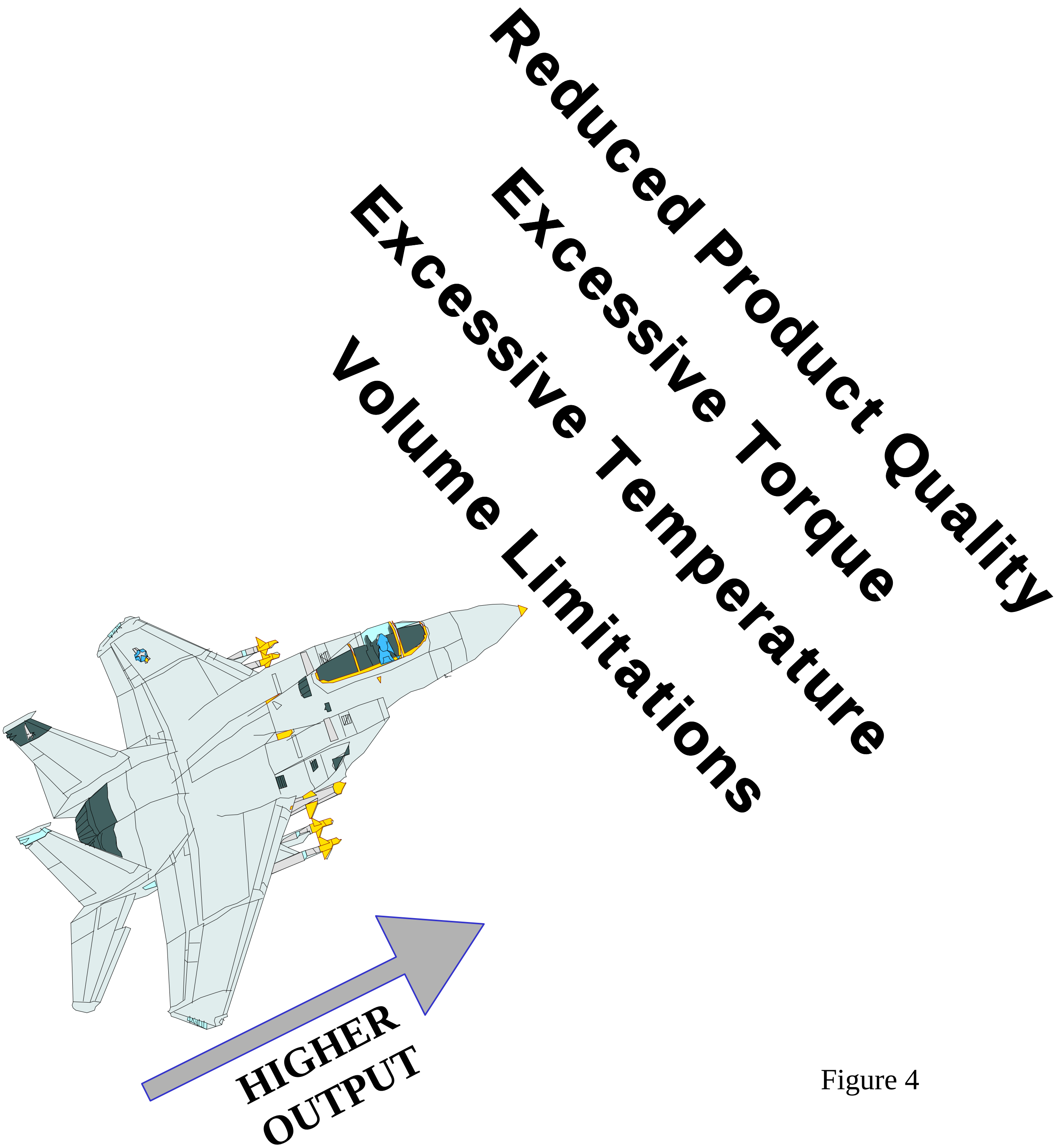

Figure 4

Table 2

40% NON-DENSIFIED ULTRAFINE TALC --- MODERATELY STRONG SCREW SET					
TOTAL OUTPUT	SCREW SPEED	TORQUE	MELT TEMP.		PLASTICS QUALITY
kg/hr (lb/hr)	RPM	%	$^{\circ}$C		
45 (100)	500	43%	295°C		EXCELLENT PROPER. , BUT MOLDED COLOR TOO YELLOW DUE TO HIGH MELT TEMP.
45 (100)	400	43%	284°C		EXCELLENT
45 (100)	300	54%	266°C		EXCELLENT
	HIGHER OUTPUTS ABOVE 45 kg/hr WERE VOLUME LIMITED DUE TO BACKUP IN THE SIDE FEEDER				

40% NON-DENSIFIED ULTRAFINE TALC --- STRONGER SCREW SET					
TOTAL OUTPUT	SCREW SPEED	TORQUE	MELT TEMP		PLASTICS QUALITY
kg/hr (lb/hr)	RPM	%	$^{\circ}$C.		
45 (100)	300	52%	247°C		EXCELLENT
	HIGHER OUTPUTS ABOVE 45 kg/hr WERE VOLUME LIMITED DUE TO BACKUP IN THE SIDE FEEDER				

Table 3

40% DENSIFIED ULTRAFINE TALC --- MODERATELY STRONG SCREW SET					
TOTAL OUTPUT	SCREW SPEED	TORQUE	MELT TEMP.		PLASTICS QUALITY
kg/hr (lb/hr)	RPM	%	^{o}C		
45 (100)	150	72%	232^{o}C		GOOD
45 (100)	300	51%	263^{o}C		EXCELLENT
91 (200)	250	92%	248^{o}C		EXCELLENT
136 (300)	450	90%	273^{o}C		EXCELLENT
	HIGHER OUTPUTS ABOVE 136 kg/hr WERE TORQUE LIMITED (WHERE LOWER SCREW SPEEDS WOULD BE NEEDED TO KEEP MELT TEMPERATURES FROM BECOMING EXCESSIVELY HIGH)				

40% DENSIFIED ULTRAFINE TALC --- STRONGER SCREW SET					
TOTAL OUTPUT	SCREW SPEED	TORQUE	MELT TEMP.		PLASTICS QUALITY
kg/hr (lb/hr)	RPM	%	^{o}C		
45 (100)	150	77%	231^{o}C		GOOD
45 (100)	300	56%	254^{o}C		EXCELLENT
91 (200)	310	89%	251^{o}C		EXCELLENT
136 (300)	500	92%	273^{o}C		EXCELLENT
	HIGHER OUTPUTS ABOVE 136 kg/hr WERE TORQUE LIMITED (WHERE LOWER SCREW SPEEDS WOULD BE NEEDED TO KEEP MELT TEMPERATURES FROM BECOMING EXCESSIVELY HIGH)				

Table 4

20% NON-DENSIFIED ULTRAFINE TALC --- MODERATELY STRONG SCREW SET					
TOTAL OUTPUT	SCREW SPEED	TORQUE	MELT TEMP.		PLASTICS QUALITY
kg/hr (lb/hr)	RPM	%	^oC		
91 (200)	350	90%	265 ^oC		EXCELLENT
	HIGHER OUTPUTS ABOVE 91 kg/hr WERE VOLUME LIMITED DUE TO BACKUP IN THE SIDE FEEDER				

20% NON-DENSIFIED ULTRAFINE TALC --- STRONGER SCREW SET					
TOTAL OUTPUT	SCREW SPEED	TORQUE	MELT TEMP.		PLASTICS QUALITY
kg/hr (lb/hr)	RPM	%	^oC		
91 (200)	410	86%	264^oC		EXCELLENT
	HIGHER OUTPUTS ABOVE 91 kg/hr WERE VOLUME LIMITED DUE TO BACKUP IN THE SIDE FEEDER				

Table 5

20% DENSIFIED ULTRAFINE TALC --- MODERATELY STRONG SCREW SET					
TOTAL OUTPUT	SCREW SPEED	TORQUE	MELT TEMP.		PLASTICS QUALITY
kg/hr (lb/hr)	RPM	%	^oC		
91 (200)	340	90%	265^oC		EXCELLENT
113 (250)	450	92%	272^oC		EXCELLENT
136 (275)	525	91%	283^oC		EXCELLENT
	HIGHER OUTPUTS ABOVE 136 kg/hr WERE TORQUE LIMITED (WHERE LOWER SCREW SPEEDS WOULD BE NEEDED TO KEEP MELT TEMPERATURES FROM BECOMING EXCESSIVELY HIGH)				

20% DENSIFIED ULTRAFINE TALC --- STRONGER SCREW SET					
TOTAL OUTPUT	SCREW SPEED	TORQUE	MELT TEMP.		PLASTICS QUALITY
kg/hr (lb/hr)	RPM	%	^oC		
9l (200)	360	91%	258^oC		EXCELLENT
113 (250)	480	91%	269^oC		EXCELLENT
136 (300)	600	94%	283^oC		EXCELLENT
	HIGHER OUTPUTS ABOVE 136 kg/hr WERE TORQUE LIMITED (WHERE LOWER SCREW SPEEDS WOULD BE NEEDED TO KEEP MELT TEMPERATURES FROM BECOMING EXCESSIVELY HIGH)				

Table 6

40% Ultrafine Talc Reinforced Polypropylene Copolymer Product Quality Results from Compounding Trial

Talc Grade		Densified Ultrafine Talc	Nondensified Ultrafine Talc
Total Maximum Output (kg/hr)		136	45
Screw Speed (RPM)		500	300
Torque		92%	52%
Melt Temperature		273°C	247°C
Plastics Quality	23°C DYNATUP IMPACT (J)	18.8	18.9
	NOTCHED IZOD IMPACT (J/m)	48.1	48.1
	FLEXUAL MODULUS (Mpa)	3,930	4,000
Limitations to Higher Output		Higher outputs above 136 kg/hr were torque limited	Higher outputs above 45 kg/hr were volume limited due to backup in the side feeder

- Output rates are 300% higher with densified talc compared to its non-densified equivalent
- Excellent plastics quality is maintained with densified product

Table 7

20% Ultrafine Talc Reinforced Polypropylene Copolymer Product Quality Results from Compounding Trial

Talc Grade		Densified Ultrafine Talc	Nondensified Ultrafine Talc
Total Maximum Output (kg/hr)		136	91
Screw Speed (RPM)		600	410
Torque		94%	86%
Melt Temperature		283°C	264°C
Plastics Quality	23°C DYNATUP IMPACT (J)	18.6	19.0
	NOTCHED IZOD IMPACT (J/m)	90.8	90.8
	FLEXUAL MODULUS (Mpa)	2,350	2,420
Limitations to Higher Output		Higher outputs above 136 kg/hr were torque limited	Higher outputs above 91 kg/hr were volume limited due to backup in the side feeder

- Output rates are 50% higher with densified talc compared to its non-densified equivalent
- Excellent plastics quality is maintained with densified product