Nano Silica Technical Paper

A Study of The Effect of Nano Silica Processing Aid For Significantly Reducing The Cycle Time in Injection Molding And Improving Strength and Toughness of PP, nylons, and PBT

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ABSTRACT

A comprehensive technical investigation was undertaken to determine the effect of Nano Silica, an ultra fine, high purity, **amorphous colloidal Silicone Dioxide** powder (see Table 1 for chemical description of the additive) on injection molding cycle time and physical properties of PP, unfilled and glass filled nylon 6, glass filled nylon 66, and unfilled PBT.

The results of this study show that at 0.4 to 0.8 weight percent concentration the Nano Silica additive is found to be very effective in significantly reducing the cycle time in injection molding and improving the strength and toughness of PP, nylon 6 and nylon 66, and PBT materials as described below:

1. The Nano Silica additive was found to be a very effective processing aid to **reduce the injection molding cycle time by 20 to 30** % in unfilled nylon 6, glass filled nylon 66, and unfilled PBT, ABS and PP (see Table 2).
2. The Nano Silica additive was found to improve the tensile strength and flexural modulus of nylons, PBT, and PP resins from 3 to 8 % (see Tables 3 to 6).
3. The Nano Silica additive was found to improve the color dispersion in injection molded parts of filled and unfilled polymers while reducing the flow lines and surface defects.
4. Brabender torque rheology data shows a reduction in loading torque and equilibrium viscosity of PP with 1 % Nano Silica additive indicating its potential use as an effective processing aid to **reduce the energy and motor torque in polymer processing.**
5. Further work is planned to investigate the usefulness of the Nano Silica additive as a heat sink and processing aid for both extrusion and injection molding of PE, PVC, PP, and nylons to reduce the cost and improve the productivity.
6. Further work is also planned to understand the mechanism of the Nano Silica additive as a reinforcement filler to potentially use it as a synergistic filler with glass fiber for faster cycle time and to reduce the mold wear in injection molding and extrusion.

Description of the Nano Silica material

Nano Silica is an ultra fine (sub micron), spherical discrete, non-fused, high purity **Amorphous Colloidal Silica Powder** produced through high temperature hydrolysis in a hydrogen oxygen flame. Due to its unique ability to work as a heat sink and processing aid, it is designed to offer specific benefits in polymer processing as described in this paper. Table 1 describes its chemical and physical properties in detail.

Outline of the Experimental Work

We have included four very important polymers in this study to determine the effect of adding the Nano Silica additive at 0.4% and 0.8% with each polymer to measure its effect on injection molding cycle time and physical properties. The injection molding grade resins considered for this study are:

1. Schulman polypropylene - Poly 1058 with melt flow index range of 8 to 10
2. Unfilled nylon 6 - Chemlon 212 - melt flow index range 8 to 10
3. Glass filled nylon 6 - Chemlon 214 G - melt flow index 7 to 9
4. BASF Ultradur unfilled PBT - melt flow index 8 to 10

The Nano Silica additive was tumble mixed for fifteen minutes in a Conair blender with each resin. The additive was found to coat the resin pellets very well and no problem was found in obtaining a uniform mix of the additive with each polymer. As shown later in the report, the dispersion of the additive was very good with each polymer based on the consistency of the physical properties of the molded specimen. As a result, we did not do any melt compounding of the additive in this study since the additive is very easy to mix with the polymer in a blender.

The three blends of each polymer were prepared and identified as control (no additive), 0.4% additive mix, and 0.8% additive mix. The blends were then injection molded on a 110 ton Cincinnati molding machine using a ASTM mold to make the tensile bars. The molded tensile bars were used to measure the physical properties of each polymer blend with the Nano Silica additive as discussed below. Three repeat molding trials were made with each polymer to test the effect of 0.8% additive on cycle time and the results are shown below.

Results and Discussion - Effect of Nano Silica on Injection Molding Cycle Time and the Physical Properties of each Polymer

Table 1 describes the chemical and physical attributes of the Nano Silica additive. It is a very free flowing powder that has unique ability to coat the resin pellet during the mixing cycle. Minimum dusting was noticed while introducing the blends in the hopper for the molding study. Each polymer was blended with the Nano Silica additive at 0, 0.4, and 0.8 weight % additive for fifteen minutes in a Conair blender. Due to the ease of the mixing of the additive, we did not do any melt blending of the additive which can be done easily for a large volume operation.

The molding trials of each blend were conducted on a 110 ton Cincinnati molding machine using an ASTM mold to produce tensile bars which were then used to measure the physical properties.

Based on our molding experience of more than twenty years, we set the melt temperature for PP and nylon 6 at 400 F while the PBT blends were molded at 500 F melt temperature. Typical cycle time to mold the ASTM test bars was determined to be approximately 30 seconds for each resin considered in this study. Generous amounts of test bars were produced from each resin using 0%, 0.4% and 0.8% Nano Silica additive. After producing the required samples for measuring the physical properties of each blend at steady state conditions using cycle time of 30 seconds as a bench mark, we then devoted considerable time to measure the effect of 0.8% Nano Silica additive on the cycle time for each material as described below.

EFFECT OF NANO SILICA ON CYCLE TIME

Table 2 shows the results of cycle time with three repeat mold trials of each resin with 0.8% Nano Silica additive. Our objective was to determine if the additive can allow one to reduce the cycle time without affecting the mold quality in terms of flow lines, splash, or warpage. As shown in Table 2, we are able to reduce the cycle time by 22 % for PP resin with the additive. The molded test bars were all checked for tolerances and surface quality. Each of the bars was found to be within the specification of the mold tolerances at reduced cycle time of 22 %.

We believe the Nano Silica additive may be working as a heat sink to reduce the amount of cooling required during the molding. We further postulate that the additive may be working as a processing aid for each polymer to reduce the shear gradients at the gate and facilitates the melt flow orientation based on the Brabender torque rheometer data shown in Figure 1. Note that 1% additive significantly lowers the loading torque and the equilibrium torque of PP resin as shown in Figure 1 indicating lower motor amps and reduced energy requirements during molding. We believe further work on this additive to determine its melt flow behavior will be very useful to broaden its applications in extrusion and injection molding to reduce the energy, shear gradients, and melt temperature due to reduced frictional heat based on our thesis that Nano Silica may be working as an effective heat sink in polymer processing.

Nylon 6 and nylon 66 are very important molding materials with large volume usage in a variety of molding applications. In this study we evaluated the effect of Nano Silica additive on cycle time for unfilled nylon 6 and 33 % glass filled nylon 66. As shown in Table 2, the additive reduces the cycle time of unfilled nylon 6 by 24 %. The results of Nano Silica are even more dramatic as reported in Table 2 to attain 32 % reduction in cycle time with 33 % glass filled nylon 66.

The effect of Nano Silica on PBT and ABS resins is equally impressive to reduce the cycle time by 25% as shown in Table 2. As we know, these two polymers along with nylons and PP are major work horses in the injection molding market and a dramatic reduction of cycle time (20 to 30%) from a small (< 1%) usage of the Nano Silica additive can be very powerful cost reduction incentive for every molder to be more competitive in the Global economy.

EFFECT OF NANO SILICA ON THE PHYSICAL PROPETIES OF PP, NYLON 6, AND PBT

Effect of 0.4 and 0.8 wt % Nano Silica additive on the physical properties were measured in great detail by using the carefully molded tensile bars from each of the three blends containing 0, 0.4, and 0.8% additive.

Tables 3 shows the ASTM physical properties of PP with Nano Silica; including tensile stress and elongation at yield, tensile stress and elongation at break, Gardner impact, and flex modulus and flex strength. As shown in the data in Table 3, tensile properties at yield are not affected much by the additive. However we see an improvement in flex modulus indicating higher toughness attributed by the additive with PP.
Table 4 shows similar results of the physical properties of unfilled nylon 6 with Nano Silica additive. The tensile properties at yield show some increase and the flex modulus and flex strength also show 3 to 8 % increase in values due to the addition of Nano Silica additive to nylon resin. It could be concluded that the Nano Silica additive may be working as an effective filler to improve the strength and toughness of these materials. The exact mechanism is not understood at this time but additional work is planned to explain the reinforcement attributes of the additive and will be reported in future work.

Table 5 shows a comparison of the physical properties of 13 % glass filled nylon 6 with a 10 % Nano Silica additive in nylon 6. As we know glass fiber increases the tensile strength and flex modulus very significantly as shown by the data of unfilled nylon vs. 13 % glass filled nylon. We wanted to see how effective the Nano Silica additive is as a filler in comparison to glass fiber with nylon. The last five rows of Table 5 show the effect of 10% Nano Silica in nylon 6. Note that the additive is found to increase the tensile strength and flex modulus of nylon 6 significantly without any glass fiber included in this matrix. Theses results indicate that the Nano Silica additive could be used in a synergistic way to use it with glass fiber to attain similar strength properties while reducing the mold wear and improving the cycle time by reducing the amount of glass fiber. An in depth study of the Nano Silica /glass fiber synergy is planned for future work with different polymers and the results will be reported in the near future.

Table 6 shows the effect of Nano Silica on the physical properties of unfilled PBT which is used in molding of electrical components very exclusively. While most of the properties remain unaffected, the strength and toughness increases as shown in the tensile strength and modulus data. What is very interesting to note is that while the Nano Silica does not show any negative effect on the physical properties and it does show 3 to 8 % increase in strength and toughness of PP, nylon, and PBT, the additive could be considered as a good reinforcement filler for these polymers reported in this study to improve tooling wear, and reduce the energy cost. **The real benefit of the Nano Silica additive is found to be the significant reduction (20 to 30 %) in cycle time** as discussed above.

EFFECT OF NANO SILICA ON COLOR DIPERSION AND FLOW LINES

We carefully examined the effect of Nano Silica in molding of PP and nylons for color dispersion ability and overall surface quality. We are pleased to report that the additive was found to be very effective in improving the color dispersion for red, yellow, and gold colorants in PP and nylons. The Nano Silica additive is also found to improve the flow lines and surface imperfections in glass filled nylon 6 and nylon 66.

CONCLUSIONS AND RECOMMENDATIOS

Based on the results of this study, we can draw the following meaningful conclusions about the effectiveness of the Nano Silica additive:

1. The Nano Silica additive was found to be very effective processing aid to **reduce the injection molding cycle time by 20 to 30 %** in unfilled PP, nylon 6, glass filled nylon 66, PBT and ABS materials.
2. The Nano Silica additive was found to be an effective reinforcement filler to improve the tensile strength and flexural modulus of nylons, PP, and PBT by 3 to 8 %.
3. The Nano Silica additive was also found to improve the **color dispersion** of the molded parts of filled and unfilled PP and nylons while reducing the flow lines and surface defects.
4. Nano Silica additive has the potential to work in synergy with glass fiber to provide good strength properties with **less wear of the tooling and reduced energy in molding of plastic parts.**
5. Brabender torque rheology data of 1 % Nano Silica additive with PP shows a significant reduction on the loading torque and lowering of the equilibrium torque. Theses results indicate the additive may be working as a **heat sink to reduce the motor torque and energy input in molding and extrusion process by reducing the frictional heat**. Additional work is required in this area to explain the melt flow behavior of the Nano Silica additive with different polymers.

At this point we are not able to explain the precise mechanism how the additive is working to reduce the cycle time and improve the strength properties with the polymers reported in this study. However, we postulate that additional work will provide better understanding of our theory that the Nano Silica is a very useful additive for injection molding applications based on its ability to work as a heat sink and presumably work as a coupling agent and a filler in synergy with glass fiber and other fillers to offer a less abrasive filler option to reduce the tooling wear with reduced energy and lower cost material formulation matrix with better melt flow orientation for both unfilled and filled polymers. New developments on the Nano Silica blends technology will be reported in the next technical paper.

Table 1: Nano Silica - Chemical and Physical Properties

Typical Chemical Properties	
Silica	99.9%
Sodium	0.01-0.03%
Aluminum	0.001-0.003 %
Iron	<0.001%
Magnesium	<0.001%
Moisture content	0.3%

Physical Properties	
Appearance	Fine white powder
Particle diameter	0.02-0.55 um
Particle shape	spherical
Bulk density	15.5 lbs/cft
Refractive index	1.46
PH (5 % aqueous solution)	4.9
Ignition loss	0.7 wt % at 1000 C
X-ray form	amorphous

Table 2: Effect of Nano Silica on Injection Molding

Each polymer contains 0.8 wt % Nano Silica additive

Material	**Test 1**	**Test 2**	**Test 3**	**Average % Cycle Time Reduction**
PP (Poly 1058)	20	23	24	**22%**
Nylon 6 (Chemlon 212)	23	25	24	**24%**
Nylon 66 (Zytel 72G33)	30	32	33	**32%**
PBT (Ultradur 4406)	26	28	25	**26%**
ABS (Highval HG6)	24	26	25	**25%**

Did not include other resin tables as we are targeted on PP

Table 6: Nano Silica - PP - Physical Properties

Sample	Test #	Tensile stress at yield	Elongation at yield percent	Tensile Stress at break	Elong at break Per cent	Tensile modulus (Psi)	Gardner Impact mean	Flex Modulus psi	Flex Strength Psi	Melting point C	Melt Flow Index
PP		(psi)		(psi)			**Energy**				
Control	1	3050	9.4	4060	610	147000	2.17	112000	3320	168	8
P-00	2	3010	9.9	4070	670	144000	2.18	113000	3400	167	8
	3	2960	9.9	3390	540	142000	2.19	113000	3340	169	
	4	2990	9.6	3170	470	150000	2.18	110000	3320	168	
	5	2970	9.7	4020	470	140000	2.18	114000	3380	168	
	Average	**3000**	**9.7**	**3740**	**550**	**145000**	**2.18**	**112000**	**3350**	**168**	**8**
	Std. Dev	36	0.2	429	58	3970		1520	36		
P-04	1	3040	8	2460	260	156000	2.14	122000	3600	163	8.3
0.40%	2	3040	9.1	2990	470	155000	2.16	121000	3500	162	8.2
Nano Silica	3	3030	9.2	3090	480	149000	2.16	121000	3560	164	
	4	2990	9.2	2980	470	153000	2.15	122000	3590	163	
	5	3000	8.9	2990	440	141000	2.14	122000	3600	163	
	Average	**3020**	**8.9**	**2900**	**420**	**151000**	**2.15**	**122000**	**3570**	**163**	**8.2**
	Std. Dev	23	0.5	251	93	6100		548	42		
P-08	1	2920	8.5	2370	430	145000	2.11	117000	3420	160	8.4
0.80%	2	2940	8.1	2620	430	143000	2.13	119000	3540	161	8.3
Nano Silica	3	2950	8.6	2330	370	149000	2.12	124000	3640	159	
	4	2900	8.1	2290	240	121000	2.12	117000	3500	161	
	5	2940	7.9	2350	230	161000	2.12	115000	3500	161	
	Average	**2930**	**8.2**	**2390**	**340**	**144000**	**2.12**	**118000**	**3520**	**160**	**8.3**
	St. Dev	20	0.3	131	99	14500		3440	80		