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Recycled Acudel® 22000 in Injection Molded Parts

The use of regrind material in the production of injection molded thermoplastic parts has always been a topic of interest in order to reduce costs while maintaining overall part performance. Additional heat histories, inherent in the production process can induce molecular weight changes that may alter the strength, stiffness, or ductility of the polymer.

In an effort to quantify the effects of using recycled Acudel® 22000 modified polyphenylsulfone (PPSU), a regrind study was initiated. Testing involved the use of both black and natural-colored resins, multiple blend ratios for the regrind, and several heat histories. Test specimens were generated to investigate both the static load bearing ability of the material and its mechanical performance under a high rate of load application (i.e., impact).

For the static case, a standard tensile test (ASTM D638) was employed as the best indicator of a change in material performance. For the high rate of load application, an instrumented impact test was selected as the results could be used to ascertain how well the material would retain its inherently ductile nature.

The molding conditions employed for the production of the regrind material and the test specimens are shown in Table 1. The barrel residence time for the material was calculated as 67.3 seconds per heat history.

Additional test specimens were molded during each material turn so that enough regrind was created to blend with virgin material to produce samples incorporating regrind levels of 25 %, 50 % and 100 % (by weight) for each successive heat history. Figure 1 shows the performance of the Acudel® material with various levels of regrind and multiple heat histories in the tensile testing.

Table 1: Process parameters for Acudel® modified PPSU regrind study sample molding

Process Parameter	Units	Steady State Value
Melt temperature	°C (°F)	371 (700)
Mold temperature	°C (°F)	149 (300)
Screw speed	rpm	70
Plasticize time	sec.	9.3
Overall cycle time	sec.	39.6
Shot size	in^3	3.47
Barrel capacity	in^3	5.90
Estimated residence time	sec.	67.3

Remarkably, the natural Acudel® 22000 grade, designated as NT 15, showed variations in both strength and modulus of less than 2 %, even with the use of 100 % regrind material and four heat histories. The black grade, designated as BK 937, displayed a variation in modulus of only 3 %, with a change in strength of less than 1 % for any individual sample in comparison to the control specimens.

Figure 1: Tensile properties test results for Acudel® 22000 NT 15 & BK 937 various regrind percentages and multiple heat histories

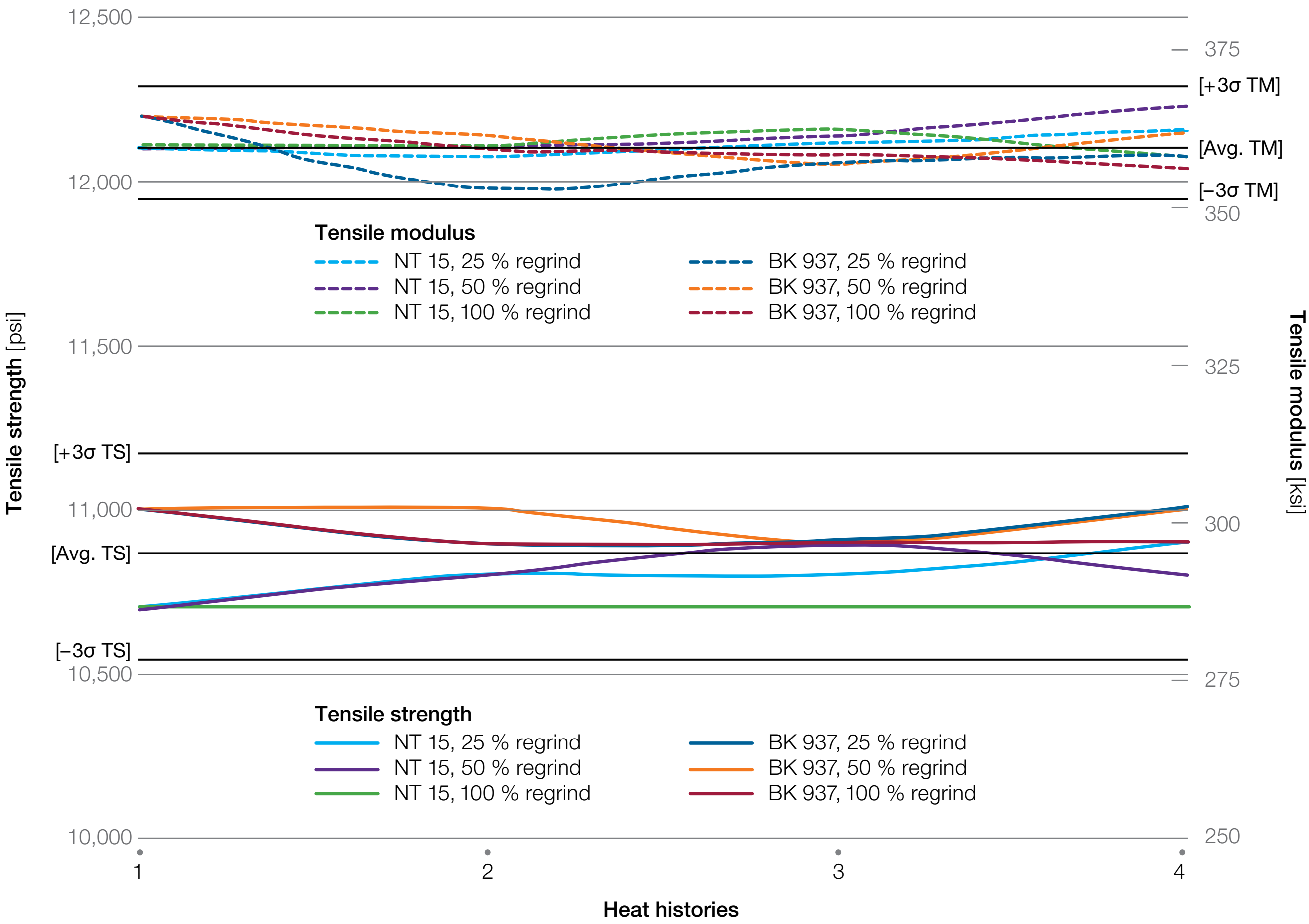
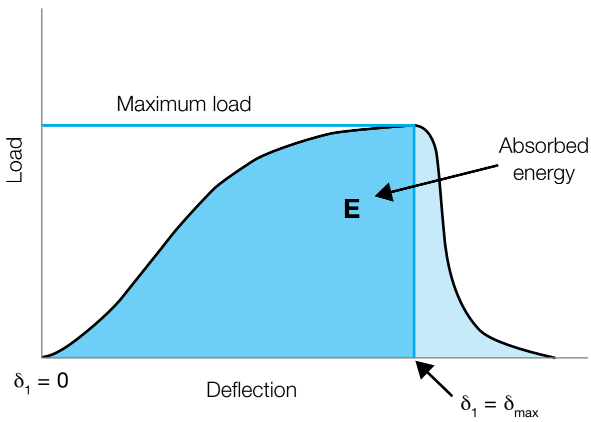


Figure 2: Typical impact performance of a ductile material



Impact energy = potential energy + kinetic energy

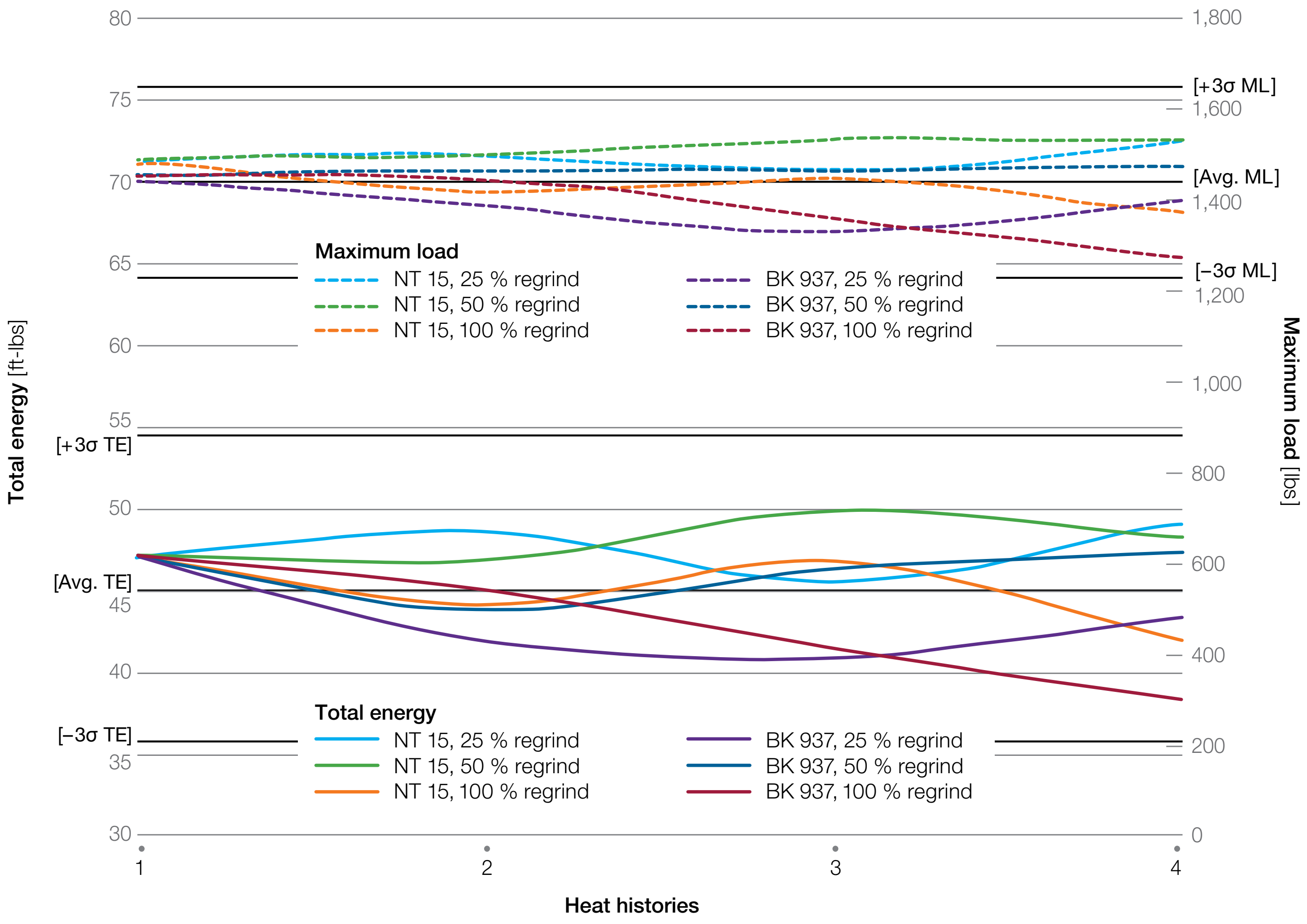
Absorbed energy = measure of material strength and ductility, shown graphically as the area beneath the load displacement curve.

The results reported for instrumented impact testing include the total energy absorbed by the test sample, as a measure of the material's ductility, and the maximum load to failure, as a measure of its load bearing ability with a rapid rate of load application. A sample graph illustrating the data collected during an instrumented impact test for a ductile material is shown in Figure 2 to assist in the understanding of why these two values are of interest. Further information on this topic is available at www.dynatup.com.

The results of the impact testing are shown in Figure 3 for Acudel® 22000 NT 15 and BK 937.

For Acudel® 22000 NT 15, the largest reductions in total energy and maximum load were 11 % and 8 %, respectively. For Acudel® 22000 BK 937, the largest reduction in total energy was 14 %, and for the maximum load 13 %. It should be noted that, for all four of these peak excursions, the specimens originated from the worst-case scenario involving the use of 100 % regrind material and four heat histories.

Figure 3: Instrumented impact test results for Acudel® 22000 NT 15 & BK 937 various regrind percentages and multiple heat histories



Melt flow testing was also performed on Acudel® 22000 with various levels of regrind incorporated. With the experimental limitations of the melt flow apparatus in mind, it may be stated that the melt flow of the material was unaffected by the regrind percentage, or the number of heat histories. The melt flow test, ASTM D1238, does not directly measure polymeric molecular weight, but it is an indicator of whether a particular sample's molecular weight has changed significantly. Based on the data listed in Table 2, it is clear that the molecular weight of Acudel® 22000 has neither increased nor decreased significantly even after four heat histories.

Based on the results of the testing performed, it may be concluded that Acudel® 22000 is a remarkably robust thermoplastic material, capable of absorbing numerous thermal cycles, while exhibiting little change in macroscopic mechanical performance. It is much more likely that industry regulations for specific applications, governing the maximum permissible level of regrind allowed for use will dictate the level of Acudel® modified PPSU regrind employed rather than any performance reduction regarding the material.

Table 2: Acudel® modfied PPSU multi-pass regrind study

Property	Units	Typical Value	Control Value	25 % Regrind (by weight) 1st Pass	25 % Regrind (by weight) 2nd Pass	25 % Regrind (by weight) 3rd Pass	50 % Regrind (by weight) 1st Pass	50 % Regrind (by weight) 2nd Pass	50 % Regrind (by weight) 3rd Pass	100 % Regrind (by weight) 1st Pass	100 % Regrind (by weight) 2nd Pass	100 % Regrind (by weight) 3rd Pass
Acudel® 22000 NT 15												
Tensile strength	psi	11,200	10,700	10,800	10,800	10,900	10,800	10,900	10,800	10,700	10,700	10,700
Tensile modulus	kpsi	390	359	358	360	362	359	361	366	360	362	358
Elongation at break	%	50	52	81	69	72	83	50	53	77	49	44
Flexural strength	psi	15,700	15,296	15,270	15,325	15,334	15,431	15,270	15,165	15,208	15,200	15,309
Flexural modulus	kpsi	400	378	373	375	373	376	373	372	375	372	375
Notched izod impact	ft-lbs/ inch	2.0	4.0	3.4	3.7	3.4	3.2	3.3	3.3	3.3	4.3	4.1
Unnotched izod impact	ft-lbs/ inch		NB(1)	NB	NB	NB	NB	NB	NB	NB	NB	NB
Instrumented impact, total energy	ft-lbs/ inch		47.2	48.6	45.6	49.1	46.8	49.8	48.2	44.1	46.8	42.0
Instrumented impact, maximum load to failure	lbs		1,485	1,495	1,457	1,523	1,496	1,527	1,527	1,415	1,443	1,369
Melt flow at 380 °C, 2.16 kg	g/10 min	12.0	10.9			10.8			11.3			11.9
CIE LAB color shift	Δ E			1.53	1.43	1.45	1.30	1.53	0.95	0.69	0.69	1.00
Acudel® 22000 BK 937												
Tensile strength	psi	11,200	11,000	10,900	10,900	11,000	11,000	10,900	11,000	10,900	10,900	10,900
Tensile modulus	kpsi	390	364	353	357	358	361	357	362	359	358	356
Elongation at break	%	50	64	45	54	60	38	68	55	48	37	33
Flexural strength	psi	15,700	15,173	15,441	15,317	15,475	15,270	15,204	15,246	15,140	15,317	15,082
Flexural modulus	kpsi	400	373	373	370	372	370	368	367	366	370	367
Notched izod impact	ft-lbs/ inch	2.0		2.9	3.2	3.4	3.2	3.8	3.1	3.5	3.3	3.2
Unnotched izod impact	ft-lbs/ inch		NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
Instrumented impact, total energy	ft-lbs/ inch		47.1	42.0	40.9	43.4	43.8	46.4	47.4	45.1	41.5	38.4
Instrumented impact, maximum load to failure	lbs		1,450	1,386	1,326	1,394	1,460	1,460	1,468	1,439	1,362	1,268
Melt flow at 380 °C, 2.16 kg	g/10 min	12.0	11.1			11.0			11.2			11.0
CIE LAB color shift	Δ E			0.18	0.02	0.10	0.11	0.16	0.12	0.23	0.17	0.17

(1) NB = No Break

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SpecialtyPolymers.EMEA@solvay.com | Europe, Middle East and Africa
SpecialtyPolymers.Americas@solvay.com | Americas
SpecialtyPolymers.Asia@solvay.com | Asia Pacific

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