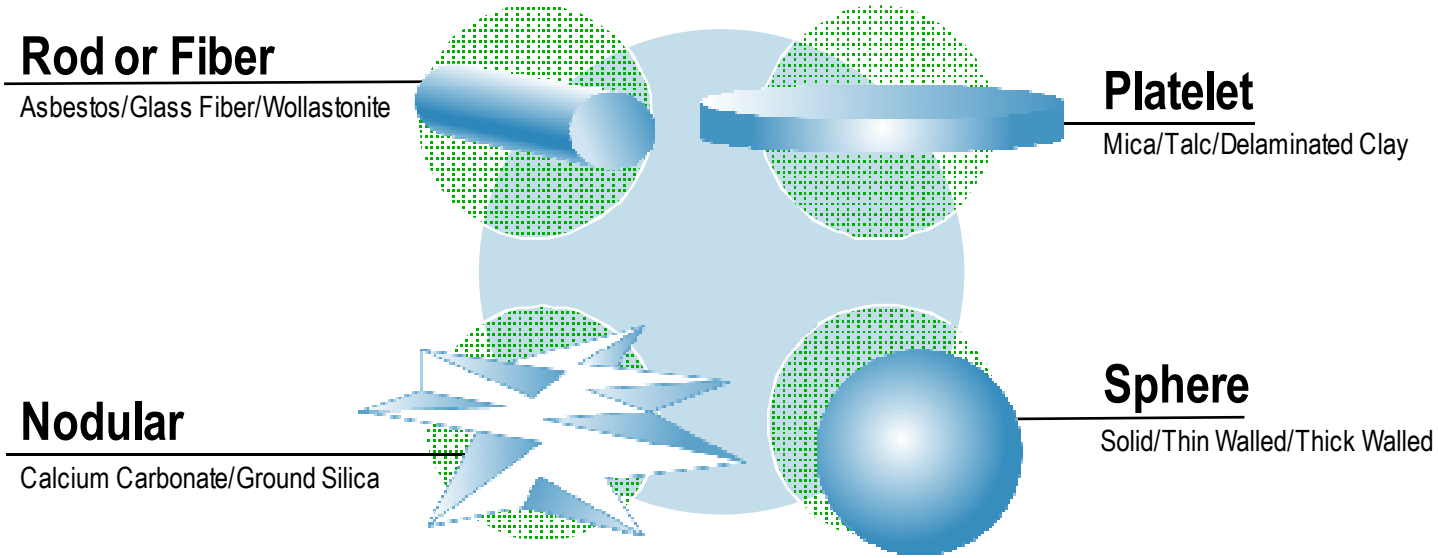

The Power
to Do More

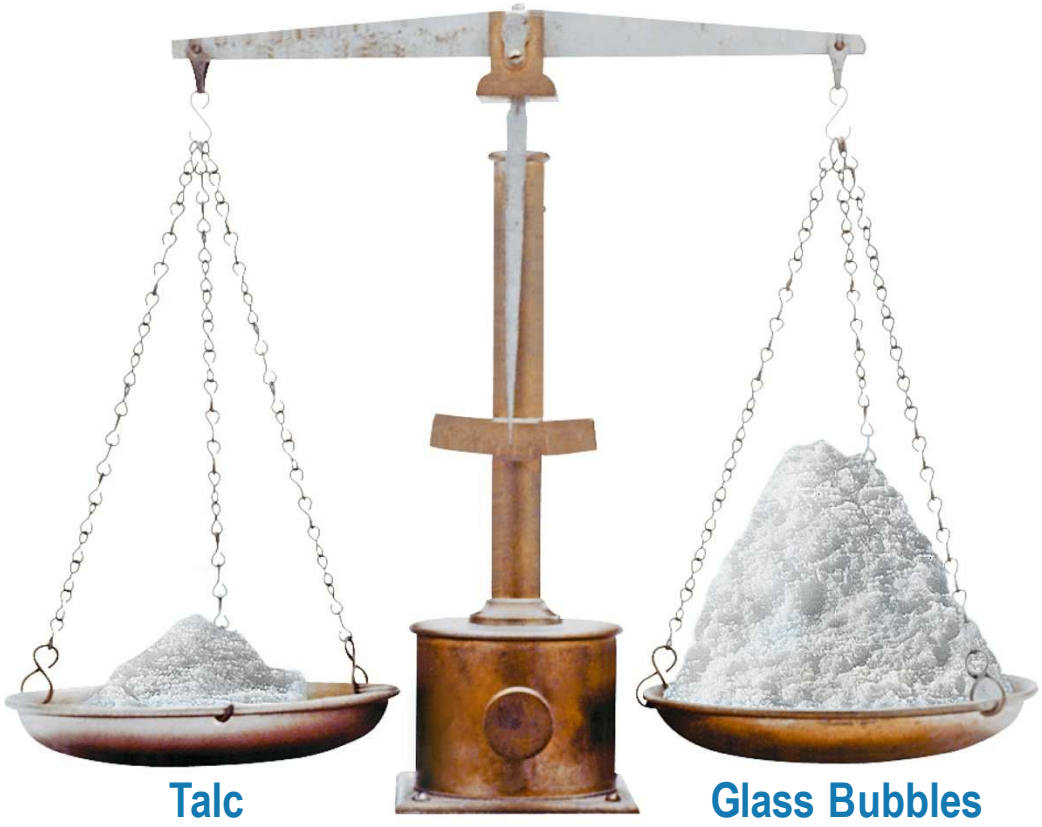
3M™ Glass Bubbles and Other Additives

Classified by Aspect Ratio



Sphere offers lowest surface area to volume ratio of any other plastic additives

3M™ Glass Bubbles and Other Additives

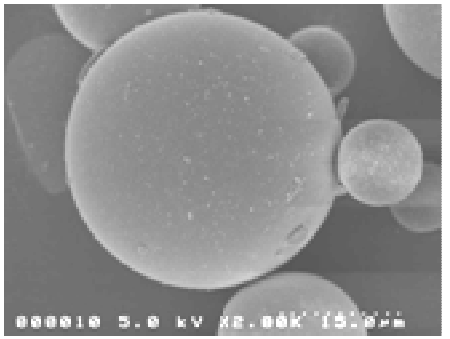


Glass bubble volume is considerably different when compared to an equal weight of higher density mineral fillers.

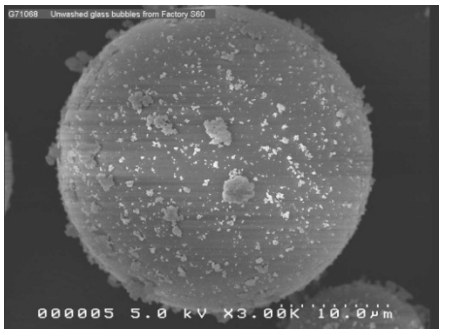
3M™ Glass Bubbles iM16K

Property	Value
Shape	**Hollow, thin walled, unicellular spheres**
Composition	**Soda-lime borosilicate glass; Chemically stable and water resistant glass**
Color	**White**
Density	**0.46 g/cc**
Crush Strength	**16,500 psi**
Hardness	**Mohs scale 5**
Softening Temp	**600° C**
Average Diameter	**20 microns**

Properties Not For Specification Purposes



Glass Bubbles as made



Glass Bubbles with silica anti-caking agent on surface

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High Strength Glass Bubbles Portfolio

3M GLASS BUBBLE	DENSITY g/cc	Strength psi	PARTICLE SIZE (microns)				AVG. WALL THICKNESS microns	VOL. % GLASS	VOL % GAS
			10 % <	50 % <	90 % <	TOP			
K37	0.37	3000	20	40	80	85	1.04	15%	85%
S38	0.38	4000	15	48	75	85	1.28	15%	85%
S38HS	0.38	5500	17	45	66	83	1.20	15%	85%
K46	0.46	6000	15	40	70	80	1.31	18%	82%
K42HS	0.42	7500	11	22	37	42	0.65	17%	83%
S60	0.60	10000	15	34	55	65	1.49	24%	76%
iM16K*	**0.46**	**16500**	**13**	**22**	**31**	**37**	**0.72**	**18%**	**82%**
S60HS	0.60	18000	11	30	50	60	1.09	24%	76%
iM30K	0.60	30000	9	16	25	29	0.70	24%	76%

Surface enhancement options available for glass bubbles

* Final Specifications are subject to change

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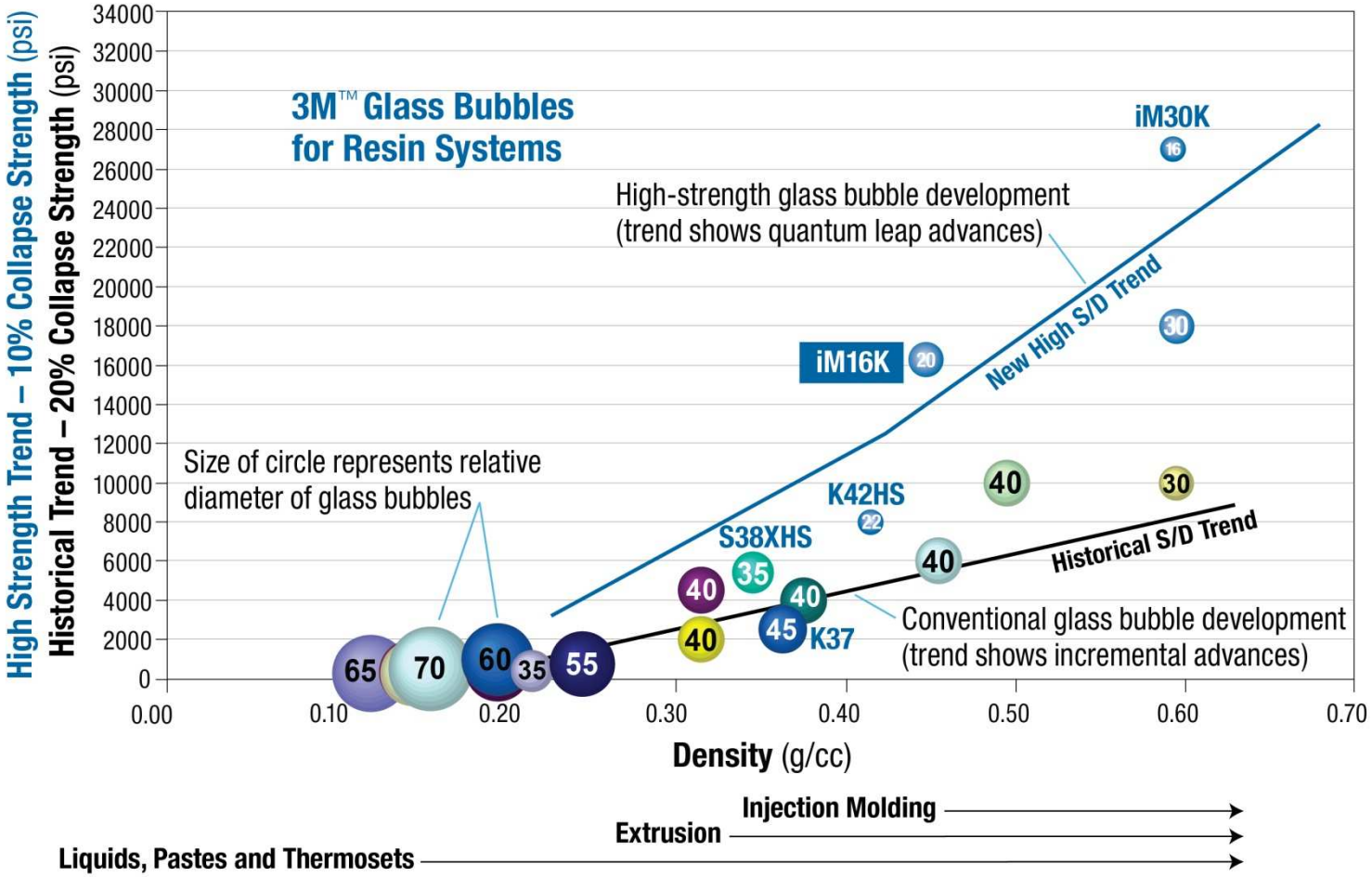
3M™ Glass Bubbles Strength to Density Map



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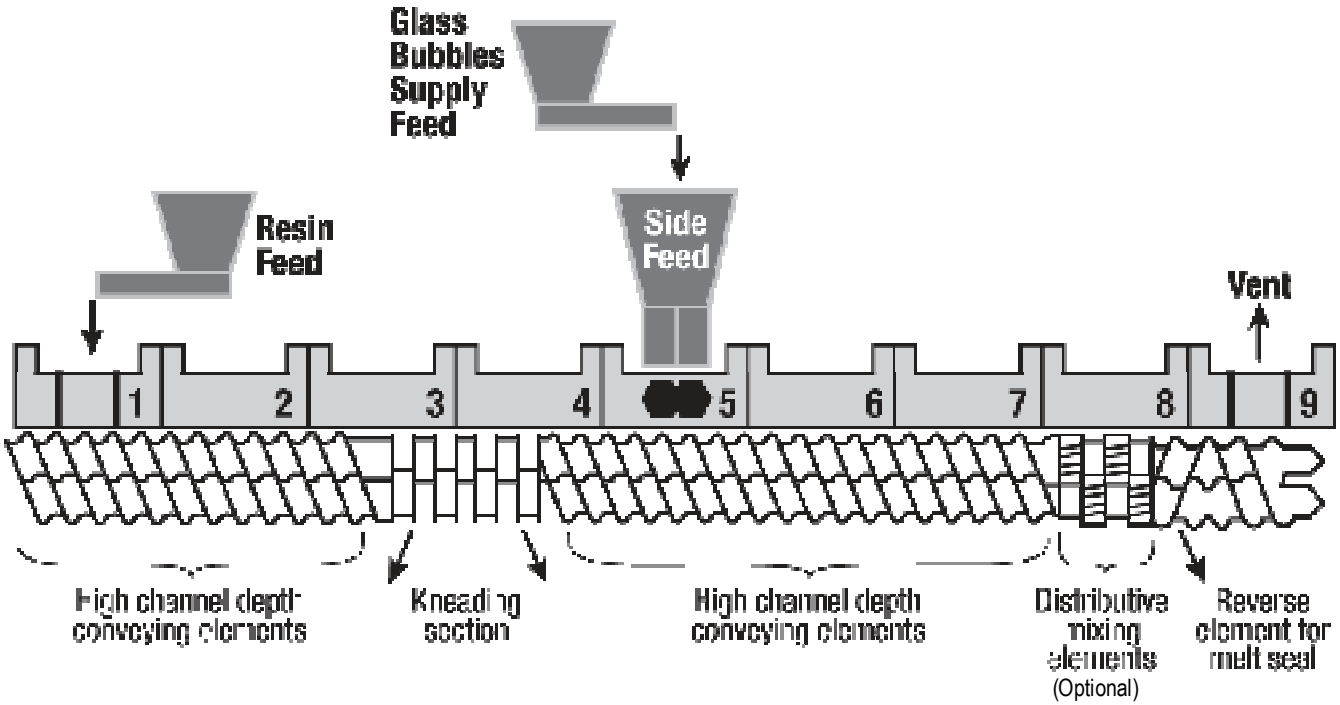
Incorporation of 3M™ Glass Bubbles via Twin Screw Extrusion



- Add glass bubbles downstream into fully molten polymer to minimize breakage
- After addition use high channel depth conveying elements
- Feeding into kneading block or conveying element with low channel depth will increase breakage

Innovative solutions may require material optimization
For assistance contact 3M Technical Experts

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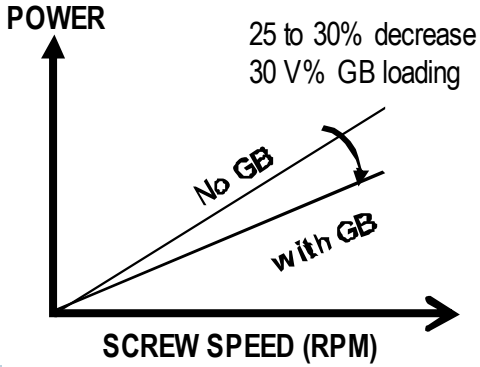
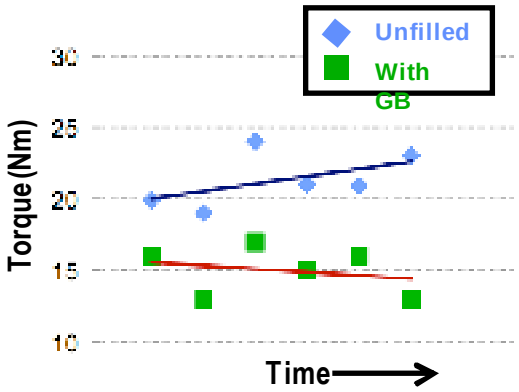
Power Requirements and Torque

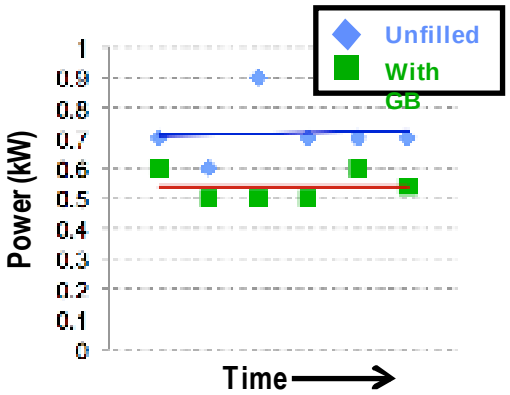
POWER = TORQUE × 2π SCREW SPEED (RPM)

Achieve higher volumetric throughput with 3M™ Glass Bubbles or reduce torque and hence power requirements for a given volumetric throughput.

Example: Homopolymer PP with and without 3M glass bubbles at 30 vol%







24 MM & L/D 28:1 (PRISM TSE 24 MC)
Measurements were taken at ~ 20 % torque level for unfilled resin

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Theoretical Weight Reduction of 3M™ Glass Bubbles in Unfilled Resins

Glass Bubbles	Volume %	Polypropylene 0.9 g/cc		Polyamide 1.14 g/cc		PEEK 1.32 g/cc	
		Weight Loading %	Weight Reduction %	Weight Loading %	Weight Reduction %	Weight Loading %	Weight Reduction %
S60HS	10	6.9	3	5.5	5	4.8	6
iM16K	**10**	**5.4**	**5**	**4.3**	**6**	**3.7**	**7**
S60HS	20	14.3	7	11.6	10	10.2	11
iM16K	**20**	**11.3**	**10**	**9.2**	**12**	**8**	**13**
S60HS	30	22.2	10	18.4	14	16.3	16
iM16K	**30**	**18**	**15**	**14.7**	**18**	**13**	**20**

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3M™ Glass Bubbles in Talc Containing TPOs

3M Glass Bubble	Wt %	PP/ 10 Talc 0.97 g/cc % Weight Reduction
S60HS	3 Talc 3 GB	6
iM16K	3 Talc, 2.3 GB	7

3M Glass Bubble	Wt %	PP/ 30 Talc 1.13g/cc % Weight Reduction
S60HS	14.5 Talc 4.5 GB	14
iM16K	14.7 Talc 3.4 GB	15

3M Glass Bubble	Wt %	PP/ 20 Talc 1.04 g/cc % Weight Reduction
S60HS	7.5 Talc, 3.2 GB	10
iM16K	7.6 Talc 2.5 GB	11

3M Glass Bubble	Wt %	PP/ 40 Talc 1.23g/cc % Weight Reduction
S60HS	20 Talc 6 GB	18
iM16K	20.5 Talc 4.8 GB	19

Critical Mechanical Properties Maintained
Flexural and Tensile Strength; Izod Impact Strength

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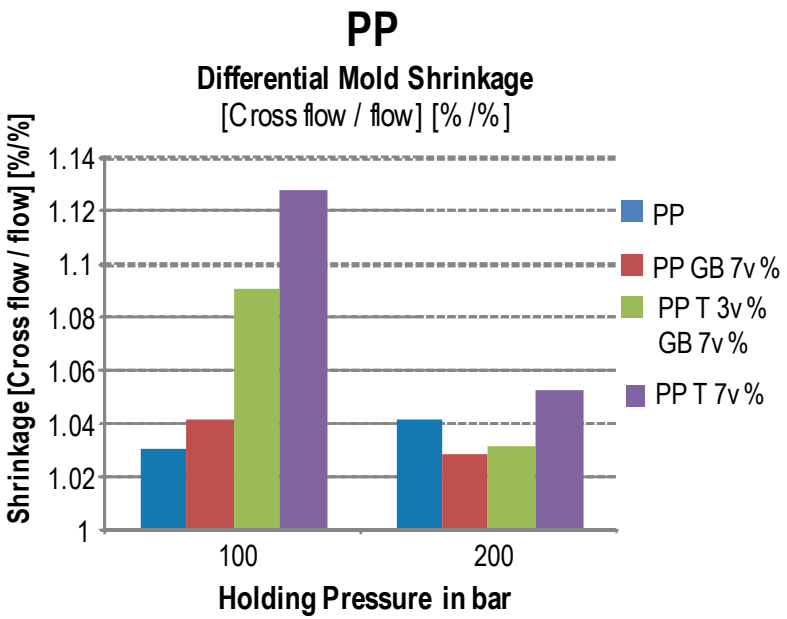
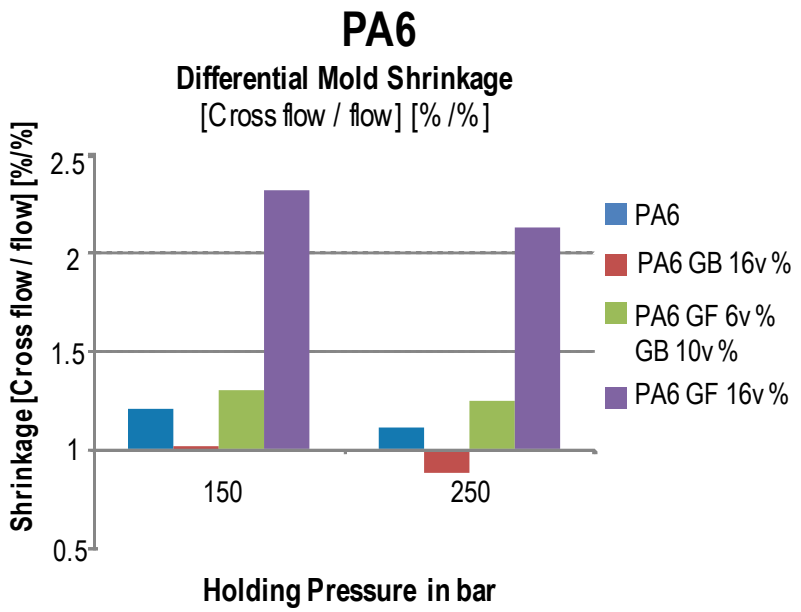
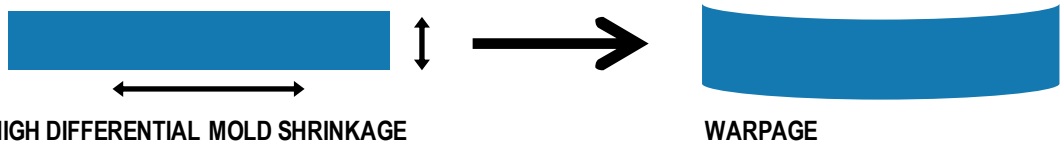
Dimensional Stability in PP and PA6

Independent Study by SKZ Institute, Germany
According to DIN EN ISO 294-4





Improve dimensional stability of molded parts by decreasing differential mold shrinkage with iM16K



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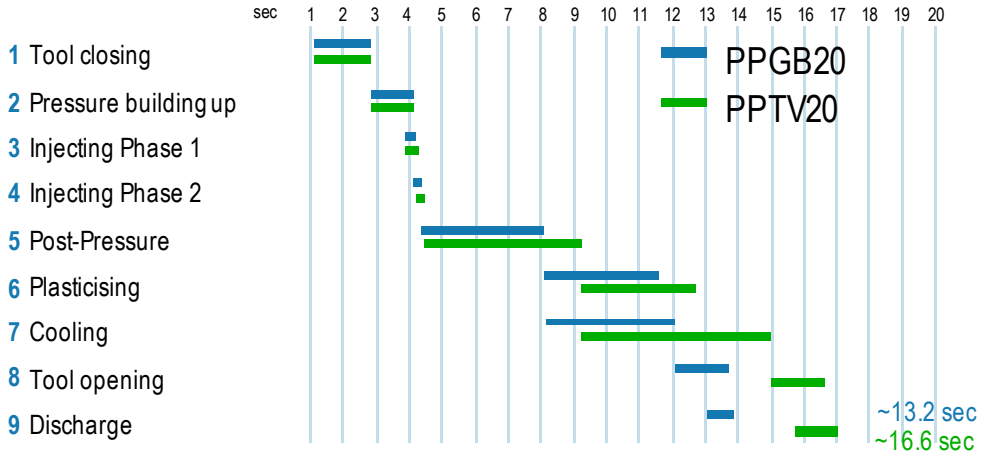
Injection Molding Cycle Time Reduction in PP

3M Cabin Air Filter Frame Containing 3M™ Glass Bubbles iM30K

Criteria	Target	PPTV20	PPGB20	D
Density (g/cc)	1.04	1.043	0.846	- 18.8 %
Length (mm)	258	257.41	258.07	- 0.59
Width (mm)	193	192.38	192.99	- 0.61
Height (mm)	30	30.07	30.02	- 0.05
Part Weight (g)	64	64.08	53.32	- 16.8 %

Molding Process for 3M CAF frames E-39



Starting formulation: PP + 20wt% talc + carbon black (PPTV20A15)
GB formulation: PP + 5wt% (=20wt.% talc) 0.6 g/cc GB + carbon black (PPGB20)

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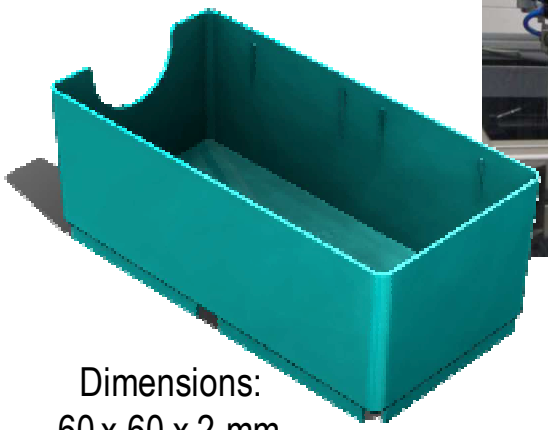
Injection Molding Cycle Time Reduction in PA6 Containing iM16K

Independent Study by SKZ Institute, Germany

Material	Total Cycle Time t_G [s]	Cycle Time Reduction in [%]
PA6	40.2	–
PA6 GB–16 v%	35.2	**12**
PA6 GF 15–6 v% GB–10 v%	38.2	**5**

Part Molded



Dimensions:
60 x 60 x 2 mm

Experimental Setup:
Ejection Temp measured by IR

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3M™ Glass Bubble Applications

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Contributing to Environmental Sustainability

Addition of 3M™ Glass Bubbles has neutral impact on carbon footprint of finished plastic parts

- Single-site carbon footprint study conducted by 3M of one class of glass bubble popular for use in plastics manufacturing
- Additional studies underway
- Common transportation application resins utilized

Plastics manufactured with 3M glass bubbles may be recycled

- Minimal change in resin properties up to 5 cycles

Lightweighting, warpage, shrinkage

Problem Solving

Delivering new and unique materials solutions

Innovation

Collaboration

Global technical expertise

DO MORE for Customers

Online training, shop 3M.com, webinars, YouTube videos, thought leadership papers

Online

Sustainability

Neutral impact on carbon footprint of finished plastic parts

Reduction of total systems costs in plastics and shipping costs for parts

For Less Money

Production

Make more parts per hour

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Impact Strength in Unfilled PP Without Impact Modifier

ASTM D256 Izod Pendulum impact strength –Test Method A- Notched (kj/m^2)	As Received Unfilled	Part with iM30K	**Part with IM16K**	Part with iM30K	**Part with iM16K**
Density g/cc	0.9	0.86	**0.86**	0.83	**0.83**
Borealis Standard PP (Homopolymer H503)	4.54	3.4	**4.16**	1.83	**3.36**
L-B Standard PP (Homopolymer- PP6523)	4.310	3.92	**4.26**	2.17	**3.96**
Borealis Copolymer (CP284)	19.16	5.89	**7.8**	3.45	5.4

At same composite density, better retention of impact strength with 3M™ Glass Bubbles iM16K

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Flexural Modulus in Unfilled PP

ASTM D790 with 3-point bend fixture Test speed 0.2 in/min Flexural Modulus 1% secant (ksi) To convert to MPa, multiply by 6.9	As Received Unfilled	Part with iM30K	**Part with IM16K**	Part with iM30K	**Part with iM16K**
Density g/cc	0.9	0.86	**0.86**	0.83	**0.83**
Borealis Standard PP (Homopolymer H503)	200	240	**220**	260	**240**
L-B Standard PP (Homopolymer- PP6523)	175	215	**200**	255	**218**
Borealis Copolymer (CP284)	156	200	**175**	225	**190**

Increased Flexural Modulus with 3M™ Glass Bubbles

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Tensile Modulus in Unfilled PP

ASTM D638 Tensile Testing Tensile Modulus (MPa)	As Received Unfilled	Part with iM30K	**Part with IM16K**	Part with iM30K	**Part with iM16K**
Density g/cc	0.9	0.86	**0.86**	0.83	**0.83**
Borealis Standard PP (Homopolymer H503)	1320	1625	**1460**	2120	**1545**
L-B Standard PP (Homopolymer- PP6523)	1100	1340	**1200**	1840	**1330**
Borealis Copolymer (CP284)	1045	1210	**1100**	1475	**1240**

At same composite density, increase in Tensile Modulus with 3M™ Glass Bubbles iM16K

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Flexural Strength in Unfilled PP

ASTM D790 with 3-point bend fixture – Test speed 0.2 in/min -Flexural Strength (ksi). To convert to MPa, multiply by 6.9	As Received Unfilled	Part with iM30K	**Part with IM16K**	Part with iM30K	**Part with iM16K**
Density g/cc	0.9	0.86	**0.86**	0.83	**0.83**
Borealis Standard PP (Homopolymer H503)	6.8	6.2	**6.4**	5.1	**6.0**
L-B Standard PP (Homopolymer- PP6523)	5.9	5.6	**5.6**	4.9	**5.5**
Borealis Copolymer (CP284)	4.9	4.3	**4.4**	3.4	**4.1**

At same composite density, good retention of Flexural Strength with 3M™ Glass Bubbles iM16K

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Tensile Strength in Unfilled PP

ASTM D638 Tensile Testing Tensile Strength at Yield (ksi). To convert to MPa, multiply by 6.9	As Received Unfilled	Part with iM30K	**Part with IM16K**	Part with iM30K	**Part with iM16K**
Density g/cc	0.9	0.86	**0.86**	0.83	**0.83**
Borealis Standard PP (Homopolymer H503)	4.97	3.55	**3.98**	2.53	**3.29**
L-B Standard PP (Homopolymer- PP6523)	4.46	3.46	**3.77**	2.48	**3.23**
Borealis Copolymer (CP284)	3.13	2.36	**2.56**	1.61	**2.2**

At same composite density, improved Tensile Strength retention with 3M™ Glass Bubbles iM16K

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TPOs Containing Talc
Partial Replacement

Component.	Formula 1		Formula 2		Formula 3		Formula 4		Formula 5		Formula 6		Formula 7	
	20wt% TALC + 8 WT% EPDM		7.35wt% TALC+ 4.4 wt% S60HS +8.8 wt% EPDM		7.52wt% TALC + 2.26 wt% iM16K + 9 WT% EPDM		6.84wt% TALC +10.94 wt% S60HS +8.2 WT% EPDM		7.25wt% TALC + 5.8 wt% iM16K + 8.7 WT% EPDM		7.25wt% TALC + 2.17 wt% iM16K + 8.7 WT% EPDM +MAPP		7.00wt% TALC + 2.31 wt% iM16K + 8.4 WT% EPDM +MAPP	
	Wt%	vol%	Wt%	vol%	Wt%	vol%	Wt%	vol%	Wt%	vol%	Wt%	vol%	Wt%	vol%
Homo-PP Albis	80	82.71	79.5	81.15	81.2	83.22	74	72.76	78.25	77.4	78.26	80.07	75.5	74.66
EPDM RUBBER	8	9.61	8.8	9.43	9.0	9.67	8.2	8.45	8.7	9.0	8.7	9.3	8.4	8.67
TALC	20	7.68	7.35	2.51	7.52	2.58	6.84	2.26	7.25	2.4	7.25	2.48	7.0	2.31
S60HS-GB			4.4	6.91			10.94	16.53						
iM16K-GB					2.26	4.53			5.8	11.22	2.17	4.35	5.6	10.83
MAPP											3.62	3.80	3.5	3.53
GB/TALC VOL RATIO	0		2.75		1.75		7.31		4.68		1.75		4.68	
Final %	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Density	1.058		0.935		0.932		0.912		0.894		0.935		0.894	
Tensile Strength (MPa)	31.2		25.9		27.7		21.9		23.3		30.9		30.6	
Tensile Elong. (%)	8		3.1		8.37		4.6		12.48		3.5		2.9	
Tensile Modulus (MPa)	2780		2272		2228		2290		2220		2017		2167	
Flexural Strength (MPa)	56		48		50		44		46		54.5		53.8	
Flexural Modulus (MPa)	1990		1620		1630		1800		1780					
RT Izod impact Strength (J/m2)	2780		2230		2390		2010		2180		2540		2380	

At equivalent density, 3M™ Glass Bubbles iM16K provide improved tensile strength, elongation and impact vs higher density bubble formulation. Adding a compatibilizer improves tensile, flex and Izod impact strength.

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TPOs Containing Talc

GBs added directly on top of Talc – Change in Volume % Loading

HOSTACOM TRC 787N	as received	iM16K	iM16K	iM16K	iM16K	iM16K	iM30K	iM30K
Composition	20 wt% Talc	19.8 wt% Talc & 1 wt% GB	19.5wt% Talc & 3wt% GB	18.5wt% Talc & 7.5 wt% GB	18wt% Talc & 10wt% GB	17wt% Talc & 15 wt% GB	18.3 wt% Talc & 8 wt% GB	16.5wt% Talc & 17.5 wt% GB
Density	1.044	1.036	1.015	0.972	0.948	0.903	0.989	0.935
Notched Izod Impact ASTM D256	59.80	41.40	23.6	18.27	16.49	11.97	19.52	13.28
Flexural Modulus 1% secant (ksi) ASTMD790- 3-point bend fixture – Test speed 0.2 in/min	195.9	230.6	212.7	202.9	215.1	208.2	211.4	202.7
Flexural Strength ASTMD790- 3-point bend fixture – Test speed 0.2 in/min ASTM D790	4.3	4.6	4.2	3.8	3.7	3.2	3.8	3.1
Tensile Modulus ASTM D638	194	212	207	213	205	207	214	251
Tensile Strength ASTM D638	18.3	18.4	15.7	13.8	12.6	10.2	13.5	10.1

By using the lower density 3M™ Glass Bubbles iM16K vs a higher density glass bubble (iM30K), more talc can be incorporated in formulations and still maintain the same composite density and critical properties.

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PP Containing Glass Fibers

Component	Formula 1		Formula 2		Formula 3		Formula 4		Formula 5	
	20wt% GF		20wt% GF 10 wt% iM30K		**20wt% GF 5 wt% iM16K**		**20wt% GF 5 wt% iM16K w/MAPP**		8 wt% iM16K	
	Wt%	**Vol%**	**Wt%**	**Vol%**	**Wt%**	**Vol%**	**Wt%**	**Vol%**	**Wt%**	**Vol%**
Homopolymer PP	80	92.07	70	75.90	75	81.81	72	78.48	92	85.45
Glass Fiber	20	7.93	20	7.47	20	7.52	20	7.51		
iM30K-GB			10	16.6						
iM16K-GB					5	10.67	5	10.67	8	14.55
MAPP							3	3.34		
Final	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Density	1.054		0.990		0.990		0.99		0.853	
Tensile Strength (Mpa)	76.9		58.2		62.6		72		29.8	
Tensile Elongation (%)	3.61		2.98		3.07		3.9		3.67	
Tensile Modulus (Mpa)	3530		3781		3921		3520		2397	
Flexural Strength (Mpa)	98.6		82.7		86.9		105		56.5	
Flexural Modulus (Mpa)	2730		3034		2744		2758		1848	
Izod impact Strength at RT (J/m)	6380		5370		5710		6000		2050	

At same composite density, 3M™ Glass Bubbles iM16K provide improved tensile strength, tensile modulus, flex strength and Izod impact strength. (2 vs 3) Adding a compatibilizer improves tensile, flex and Izod impact strength. (3 vs 4) Equivalent volume replacement of glass fibers with glass bubbles provides significant weight reduction but physical properties degrade further. (5 vs all)

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Nylon 66 with 10wt.% Glass Fiber
Comparison of Glass Bubble Containing Systems

Component	Formula 1		Formula 2		Formula 3		Formula 4	
	PA 6,6 Base Resin + 10w% Glass Fiber		PA 6,6 Base Resin + 10w% Glass Fiber + 6w% iM30K		PA 6,6 Base Resin + 10w% Glass Fiber + 4.7w% iM16K		PA 6,6 Base Resin + 10w% Glass Fiber + 10w% iM16K	
	Wt%	vol%	Wt%	vol%	Wt%	vol%	Wt%	vol%
PA 6,6	90	95.3	84	83.9	85.3	83.9	80	72.9
Glass Fiber	10	4.7	10	4.5	10	4.4	10	4.1
iM30K-GB			6.0	11.6				
iM16K-GB					4.7	11.7	10	23
GB/GF VOL RATIO			2.6		2.7		5.6	
Final %	100	100	100	100	100	100	100	100
Vol.% Glass	4.7		16.1		16.1		27.1	
Density	1.21		1.14		1.12		1.04	
Tensile Strength (MPa)	102		106		102		94	
Tensile Elong. (%)	5		5.7		5.2		4.7	
Tensile Modulus (MPa)	2565		2661		2524		2643	
Flexural Modulus (MPa)	3924		4276		4037		4204	
RT Izod impact Strength (KJ/m2)	5.1		3.2		3.3		2.9	

A 10wt.% glass fiber filled formulation with 4.7wt.% 3M™ Glass Bubbles iM16K provides similar tensile strength, elongation, tensile and flexural modulus to 10wt.% glass fiber with 7.5% density reduction. Doubling the iM16K wt.% has minimal further reduction in physical properties and 14% density reduction.

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Nylon 66 with 20wt.% Glass Fiber
Comparison of Glass Bubble Containing Systems

Component	Formula 1		Formula 2		Formula 3		Formula 4	
	PA 6,6 Base Resin + 20w% Glass Fiber		PA 6,6 Base Resin + 20w% Glass Fiber+ 5w% iM30K		PA 6,6 Base Resin + 20w% Glass Fiber + 3w% iM16K		PA 6,6 Base Resin + 30w% Glass Fiber	
	Wt%	vol%	Wt%	vol%	**Wt%**	**vol%**	Wt%	vol%
PA 6,6	80	90	80	83.9	**85.3**	**83.9**	70	83.9
Glass Fiber	20	10	20	9.8	**20**	**9.7**	30	16.1
iM30K-GB			5.0	6.3				
iM16K-GB					**3**	**6.4**		
GB/GF VOL RATIO			0.65		**0.66**			
Final %	100	100	100	100	**100**	**100**	100	100
Vol.% Glass	10		16.1		**16.1**		16.1	
Density	1.28		1.24		**1.23**		1.37	
Tensile Strength (MPa)	138.5		149.2		**151.7**		191.4	
Tensile Elong. (%)	5.4		6.1		**6.2**		6.6	
Tensile Modulus (MPa)	3311		3502		**3444**		4454	
Flexural Modulus (MPa)	5453		6022		**5811**		7470	
RT Izod impact Strength (kJ/m2)	6.0		6.0		**6.3**		8.9	

A 20wt.% glass fiber filled system with 3% iM16K has equivalent physical properties to 20wt.% glass fiber filled Nylon 66 and 4% density reduction.

At equivalent volume % of glass as a standard 30wt.% glass fiber formulation, 3M™ Glass Bubbles iM16K with 20wt.% glass fiber reduces density by 10% and provides 70% of impact strength, 80% of tensile strength and tensile modulus and 90% of flexural modulus.

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Nylon 66 with 30wt.% Glass Fiber
Comparison of Glass Bubble Containing Systems

Component	Formula 1		Formula 2		Formula 3		Formula 4		Formula 5	
	PA 6,6 Base Resin + 30w% Glass Fiber		PA 6,6 Base Resin + 30w% Glass Fiber + 5w% iM16K		PA 6,6 Base Resin + 30w% Glass Fiber + 10w% iM16K		PA 6,6 Base Resin + 20w% Glass Fiber + 3w% iM16K		PA 6,6 Base Resin + 20w% Glass Fiber	
	Wt%	vol%	Wt%	vol%	Wt%	vol%	Wt%	vol%	Wt%	vol%
PA 6,6	70	83.9	65	71.4	60	60.8	85.3	83.9	80	90
Glass Fiber	30	16.1	30	14.7	30	13.6	20	9.7	20	10
iM30K-GB										
iM16K-GB			5	13.9	10	25.6	3	6.4		
GB/GF VOL RATIO			0.94		1.9		0.66			
Final %	100		100	100	100	100	100	100	100	
Vol.% Glass	16.1		28.6		39.2		16.1		10	
Density	1.37		1.25		1.15		1.23		1.28	
Tensile Strength (MPa)	191.4		176.9		164.1		151.7		138.5	
Tensile Elong. (%)	6.6		6.3		5.4		6.2		5.4	
Tensile Modulus (MPa)	4454		4434		4595		3444		3311	
Flexural Modulus (MPa)	7470		7598		8044		5811		5453	
RT Izod impact Strength (kJ/m2)	8.9		8.6		7.7		6.3		6.0	

A 30wt.% glass fiber filled system with 5% iM16K has equivalent physical properties (except for a slight – 7.5% - drop in tensile strength) to 30wt.% glass fiber filled Nylon 66 and 9% density reduction.

A 30wt.% glass fiber filled system with 10% iM16K has an 8% increase in flexular modulus, 14.3% drop in tensile strength and 13.5% drop in impact strength compared to 30wt.% glass fiber filled Nylon 66 and 16% density reduction.

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