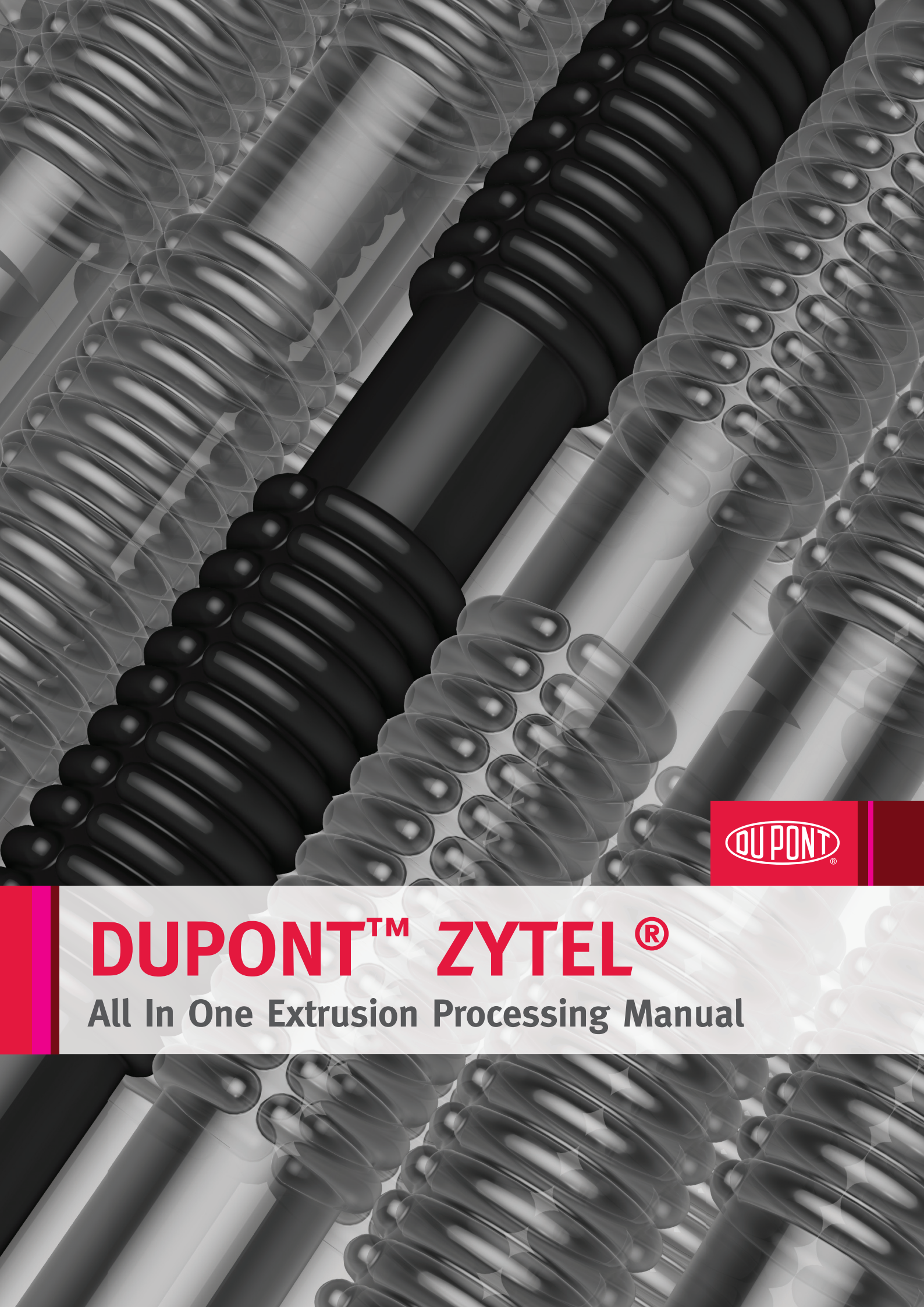
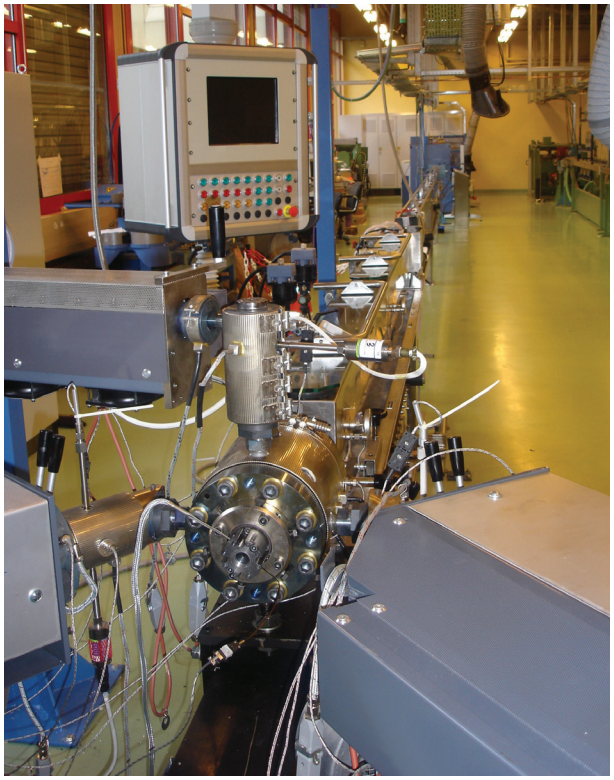


DUPONT™ ZYTEL®

All In One Extrusion Processing Manual

Thermoplastic Polyamide



MULTILAYER TUBING EXTRUSION LINE

HIGH PERFORMANCE & RESISTANCE

DuPont™ Zytel® is a trademark from DuPont for its thermoplastic polyamide resins and alloys. Since their invention by DuPont over 50 years ago, they have been the most widely used of all engineering plastics. They are tough, withstand repeated impact, and are highly resistant to abrasion and most chemicals. All types of Zytel®, including PA6, PA66, PA610, PA612, PA1010, and Zytel® FN alloys share the following general characteristics:

- Very good high temperature properties
- Excellent toughness and overall mechanical properties
- Very good resistance to a wide range of fluids and chemicals
- Low permeability to many fluids and gases, including air and fuel (non-alcohol types)

CUSTOMIZED PRODUCT RANGE

Zytel® grades may be grouped into two main categories:

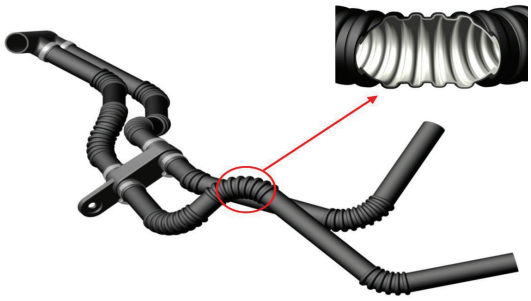
- Long chain polyamide resins
- General purpose resins

Each type has its own special features which make it the preferred choice in particular applications.

Long chain polyamide resins are available in six different series:

Zytel® RS LC1000 series products are based on PA1010 polymer, and are 20 to 100% by weight made from castor plant derived renewable monomers. They offer the best combination of performance, lowest moisture absorption in family, excellent salt resistance and hydrolytic stability, high temperature properties; commercial in diesel fuel line and truck air brake tubes; suitable for biodiesel and gasoline applications.

Zytel® RS LC2000 series comprises products based on blends of long chain polyamides, and are 20 to 100% by weight made from castor plant derived renewable monomers. They offer a unique balance of physical properties and chemical resistance, higher temperature performance, good salt resistance; commercial in air brake tubes, hand held devices; suitable for fuel applications.



TWO-LAYERS COOLANT TUBES

Zytel® RS LC3000 series products are based on PA610 homopolymer chemistry, and are 20 to 63% by weight made from castor plant derived renewable monomers. They offer the highest melting point, the best temperature performance in the family; commercial in fuel connectors, extruded products and radiator end tanks.

Zytel® RS LC4000 series products are based on chemically modified PA610 polymer, and are 20 to 60% by weight made from castor plant derived renewable monomers. Chemically modified to enhance salt resistance and flexibility, they offer a good balance of high temperature performances, fuel and hydrocarbon resistance, hydrolytic stability. Commercial in fuel line applications.

Zytel® LC6000 series products are based on PA612 homopolymer. They offer excellent high temperature performances, excellent chemical resistance to polar fluids; commercial in industrial extruded products, automotive sensors, wire and cable.

SERVO-BRAKE VACUUM TUBES

Zytel® LC7000 series products are based on chemically modified PA612. They offer excellent salt resistance and flexibility, excellent combination of cold impact toughness, high temperature properties; fuel and hydrolytic resistance. Commercial in air brake tubes, fuel lines and industrial hoses and tubes.

For general purpose resins, two families are available:

Zytel® PA6 based polymers exhibit good all-round mechanical and thermal behavior. Many of them have a formulation to reach extra performances and flexibility . They are easy to extrude.

Zytel® PA66 based polymers offer excellent performance especially in the retention of mechanical properties at elevated temperatures.

Zytel® resins are available in 25 kg bags, 1000 kg octabins and bulk containers.

IMPORTANT CHECK-LIST before processing

- Use Zytel® resin from sealed, undamaged containers.
- Dry Zytel® before the extrusion and check the moisture content. The suggested values are reported in the table on page 4.
- Drying temperature of polyamide resins should not exceed 90°C (195°F). A higher temperature could cause oxidation of polyamide polymers leading to discoloration of some grades.
- A clean extruder is preferred. Polyethylene, generally HDPE is recommended to purge barrel and screw at the end of a production to clean the equipment.
- If concentrates or pigments are added, they should be dried.
- Standard 3-zone screws are usually recommended to process Zytel®. The best results are observed when the screw has a compression ratio of 3 and L/D of 25 or higher and a design with equal length for feed, transition (compression) and metering zones.
- When needed, stainless steel screen pack unit of 80-mesh could be used for Zytel®.
- For tubing by vacuum calibration, a Draw-Down Ratio (DDR) in the range of 1.5 to 3.5 and a Draw Ratio Balance (DRB) close to 1 (0.95 to 1.05 is acceptable) are optimum.
- Follow the advised temperature profiles. As a general point the process melt temperature of Zytel® should be 15 to 30°C (25-55°F) above the nominal melting point. Thermal degradation can occur with excessive time and temperature conditions.
- Local Exhaust Ventilation should be used - refer to page 6.

DRYING PARAMETERS AND VISCOSITY OF DUPONT™ ZYTEL®

Grades				Drying		Max moisture level	Melt viscosity at rate 1000 s^{-1}	Viscosity number
Name		Resin Identification ISO1043		Temp (°C / °F)	Time (h)	%	Pa.s	cm^3/g
DuPont™ Zytel® Long Chain Polyamide								
Series 1000	RS LC1000	PA1010		80 °C 175 °F	3-4	0.06	330 (220°C)	127
	RS LC1010	PA1010			3-4	0.06	230 (250°C)	111
	RS LC1200	PA1010-HI			3-4	0.06	500 (220°C)	
	RS LC1201	PA1010-I			3-4	0.06	230 (230°C)	
	RS LC1600	PA1010-HIP	△		3-4	0.06	330 (250°C)	
	RS LC1610	PA1010-IP	△		3-4	0.06	240 (250°C)	
	RS LC1800	PA1010-P	△		3-4	0.06	160 (250°C)	
Series 2000	RS LC2600	LCPA Blends	△		3-4	0.06	330 (250°C)	
	RS LC2800	LCPA Blends	△		3-4	0.06	180 (250°C)	
Series 3000	RS LC3030	PA610			3-4	0.06	58 (250°C)	102
	RS LC3060	PA610			3-4	0.06	300 (235°C)	149
	RS LC3090	PA610			3-4	0.06	345 (240°C)	171
Series 4000	RS LC4601	Chemically modified PA610	△		3-4	0.06	330 (250°C)	
	RS LC4602	Chemically modified PA610	△		3-4	0.06		
Series 6000	151, 151L	PA612			3-4	0.06	70 (235°C)	95
	153 HSL	PA612			3-4	0.06	100 (250°C)	110
	157 HSL	PA612			3-4	0.06	140 (240°C)	115
	158, 158L	PA612			3-4	0.06	180 (235°C)	120
	159, 159L	PA612			3-4	0.06	275 (250°C)	160
	FE310001	PA612			3-4	0.06	275 (250°C)	139
	FE3734	PA612			3-4	0.06	50 (250°C)	95
	LC6200, LC6210	PA612			3-4	0.06	180 (280°C)	
	350PHS2	PA612-IP	△		3-4	0.06	320 (240°C)	
Series 7000	LC7601	Chemically modified PA612	△		3-4	0.06	370 (240°C)	
	LC7602	Chemically modified PA612	△		3-4	0.06	445 (225°C)	
DuPont™ Zytel® PA6 & PA66 for extrusion								
PA6	BM7300THS	PA6-I		80 °C 175 °F	4-6	0.06	430 (250°C)	
	BM73G15THS	PA6-IGF15			4-6	0.06	480 (250°C)	140
	FN727	PA6-F			4-6	0.06	240 (250°C)	55
	ST811HS	PA6-HI			4-6	0.06	370 (250°C)	200
	ST7301	PA6-HI			4-6	0.06	200 (280°C)	150
PA66	101, 101L	PA66			4-6	0.06	90 (290°C)	145
	103HSL	PA66			4-6	0.06	140 (280°C)	145
	CFE8005HS	PA66-HI			4-6	0.06	300 (280°C)	140
	FN714	PA66-F			4-6	0.06	270 (280°C)	
	FN718	PA66-F			4-6	0.06	310 (280°C)	
	BM70G20HSLX	PA66-IGF20			4-6	0.06	240 (290°C)	155
	ST801	PA66-HI			4-6	0.06	190 (295°C)	150
	E40	PA66			4-6	0.06	240 (290°C)	220
	E41HSB	PA66			4-6	0.06	260 (290°C)	220
	42A, E42A, E42L	PA66			4-6	0.06	270 (290°C)	280
	E50	PA66			4-6	0.06	350 (280°C)	300
	E51HSB	PA66			4-6	0.06	300 (290°C)	330
	E53	PA66			4-6	0.06	340 (290°C)	350
	70G33HSL	PA66-GF33			4-6	0.06	190 (290°C)	130

△ = plasticized

For the processing of plasticized materials, it is advised that a desiccant dryer equipped with a condenser is used to prevent contamination of the desiccant.

IMPORTANT: Before any development with the above listed grades, please check the availability of the material with your DuPont representative.

TEMPERATURE PROFILES FOR DUPONT™ ZYTEL® PROCESSING

Grades		Typical temperature settings (°C / °F)						
Name		Nominal melting point	Rear	Center rear	Center front	Front	Head and Die	Melt Temp
DuPont™ Zytel® Long Chain Polyamide								
Series 1000	RS LC1000	203 *397*	195-215 *385-420*	210-215 *410-420*	215-225 *420-435*	220-235 *430-455*	220-235 *430-455*	220-235 *430-455*
	RS LC1010							
	RS LC1200	200 *392*	190-210 *375-410*	205-210 *400-410*	210-220 *410-430*	215-230 *420-445*	215-230 *420-445*	215-230 *420-445*
	RS LC1201	201 *394*						
	RS LC1600	197 *387*	185-205 *365-400*	200-205 *390-400*	205-215 *400-420*	210-225 *410-435*	210-225 *410-435*	210-225 *410-435*
	RS LC1610							
	RS LC1800	196 *385*	185-205 *365-400*	200-205 *390-400*	205-215 *400-420*	210-225 *410-435*	210-225 *410-435*	210-225 *410-435*
Series 2000	RS LC2600	216 *421*	205-225 *400-435*	220-225 *430-435*	225-235 *435-455*	230-245 *445-475*	230-245 *445-475*	230-245 *445-475*
	RS LC2800							
Series 3000	RS LC3030	225 *437*	215-235 *420-455*	230-235 *445-455*	235-245 *455-475*	240-255 *465-490*	240-255 *465-490*	240-255 *465-490*
	RS LC3060							
	RS LC3090							
Series 4000	RS LC4601	215 *419*	205-225 *400-435*	220-225 *430-435*	225-235 *435-455*	230-245 *445-475*	230-245 *445-475*	230-245 *445-475*
	RS LC4602							
Series 6000	151, 151L	218 *424*	210-230 *410-445*	225-230 *435-445*	230-240 *445-465*	235-250 *455-480*	235-250 *455-480*	235-250 *455-480*
	153 HSL							
	157 HSL							
	158, 158L							
	159, 159L	216 *421*	205-225 *400-435*	220-225 *430-435*	225-235 *435-455*	*230-245* *445-475*	230-245 *445-475*	230-245 *445-475*
	FE310001	218 *424*	210-230 *410-445*	225-230 *435-445*	230-240 *445-465*	235-250 *455-480*	235-250 *455-480*	235-250 *455-480*
	FE3734							
	LC6200, LC6210							
	350PHS2	213 *415*	205-225 *400-435*	220-225 *430-435*	225-235 *435-455*	230-245 *445-475*	230-245 *445-475*	230-245 *445-475*
Series 7000	LC7601	209 *408*	200-220 *390-430*	215-220 *420-430*	220-230 *430-445*	225-240 *435-465*	225-240 *435-465*	225-240 *435-465*
	LC7602							
DuPont™ Zytel® PA6 & PA66 for extrusion								
PA6	BM7300THS	221 *430*	210-230 *410-445*	225-230 *435-445*	230-240 *445-465*	235-250 *455-480*	235-250 *455-480*	235-250 *455-480*
	BM73G15THS							
	FN727							
	ST811HS	218 *424*						
	ST7301	221 *430*						
PA66	101, 101L	262 *504*	250-270 *480-520*	265-270 *510-520*	270-280 *520-535*	275-290 *525-555*	275-290 *525-555*	275-290 *525-555*
	103HSL							
	CFE8005HS	260 *500*						
	FN714	263 *505*						
	FN718							
	BM70G20HSLX							
	ST801							
	E40							
	E41HSB							
	42A, E42A, E42L							
	E50							
	E51HSB							
	E53							
	70G33HSL							

For the processing of plasticized materials, please refer to the specific precautions given on page 6

IMPORTANT: Before any development with the above listed grades, please check the availability of the material with your DuPont representative.

Typical practices for DuPont™ Zytel® Extrusion

SAFETY PRECAUTIONS

Thermal degradation can occur with excessive time and temperature conditions and cause the evolution of harmful vapors. However, under normal operating conditions, the risk of decomposition of these resins is minimal. It is necessary to refer to the Safety Datasheet (SDS) before handling and using the material, to use appropriate workplace ventilation, to wear appropriate personal protection as needed.

For plasticized materials

Our plasticized materials incorporate an additive which is widely used in the industry for plasticized polyamide resins to increase their flexibility and toughness. This plasticizer may volatilize at elevated temperatures (e.g. during drying, processing, shaping, assembly). Local Exhaust Ventilation should be used to capture and remove these fumes. Please refer to our brochure *Proper use of Local Exhaust Ventilation during processing of plastics*. Since the vapors of the plasticizer and other volatiles may condense on cold surfaces, we recommend to use Neoprene or nitrile gloves when needed to protect against direct skin contact with the condensate. Please refer to the current SDS for further information.

DRYING

DuPont™ Zytel® granules are supplied in moisture resistant packaging, typically at a moisture content of less than 0.18%. When exposed to air, the granules pick up moisture; the suggested limit for processing can be reached in less than 30 min. This may result in a decrease of quality e.g. bubbles in the extrudate, drop in viscosity, reduced melt strength and low mechanical properties. Drying time and temperature will depend on the grade of resin and the initial moisture level in the material, as well as the type of drier or oven used. Therefore, general guidelines given in the table (page 4) can be adapted, as long as the polymer does not suffer from degradation. For the drying equipment, the recommended dew point is between -35°C and -40°C to guarantee efficient drying of the polymer. Drier exhausts should not be discharged into the workplace air.

For drying plasticized materials, it is advised to use a desiccant dryer equipped with a condenser to prevent contamination of the desiccant. During maintenance, Neoprene or nitrile gloves should be worn to protect against direct skin contact with the condensate. Condensate should be disposed of in accordance with local regulation.

TEMPERATURE SETTINGS

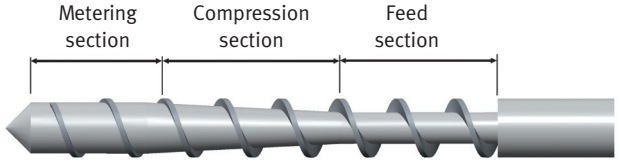
Typically, the melt temperature of Zytel® resins during extrusion should be 15-30°C (25-55°F) above the nominal melting point, with the extruder running at normal operating speed.

Occasionally it may be necessary to use temperature settings that differ from these guidelines. For example, it might be necessary to increase the die temperature 25-45°C (45-80°F) above the desired melt temperature to improve surface finish and reduce shear orientation through small die openings.

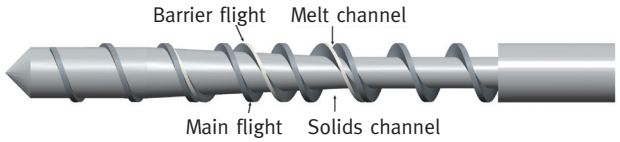
SCREW

Standard 3-zone screws are usually recommended to process Zytel® with equal length for feed, transition (compression) and metering zones as shown in the table below. The best results are observed when the screw has a compression ratio of 3 and L/D of 25. Barrier screws are also appropriate for processing Zytel ®, the double flight design provides better melt homogeneity for high speed extrusion.

Standard screw



Barrier screw



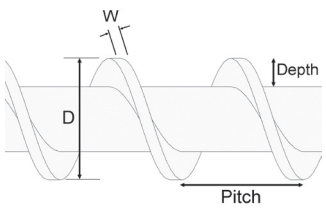
SCREW DIMENSIONS

Low viscosity resin: (‹250Pa.s)

D (mm)	Pitch (mm)	Feed channel depth (mm)	Metering channel depth (mm)	Flight width W (mm)
32	32	8	2	3
38	38	8	2	4
50	50	8	2	5
63	63	9	2	7
90	90	10	3	9
115	115	11	3	12

High viscosity resin: (›250Pa.s)

D (mm)	Pitch (mm)	Feed channel depth (mm)	Metering channel depth (mm)	Flight width W (mm)
32	32	8	2	3
38	38	8	3	4
50	50	9	3	5
63	63	10	3	7
90	90	10	3	9
115	115	12	4	12



SCREEN PACK

Stainless steel pack units of 80-mesh are generally used for Zytel®. Occasionally, it may be necessary to use finer mesh screens (e.g. supported 120 or 150-mesh) to increase back pressure.

TUBING EXTRUSION: SPECIFIC PARAMETERS

To extrude successfully a tube of a given resin and diameter, the dimensions of the extruder die and pin should be calculated considering the following formulas.

Draw-Down Ratio (DDR) is defined here as the ratio of the cross-sectional area of the extrudate at the extrusion die-face, to the cross sectional area of the finished tube.

$$DDR = \frac{(D_d^2 - D_m^2)}{(D_t^2 - D_b^2)}$$

Draw Down Ratio

The Draw Ratio Balance (DRB) for all DuPont grades should be around 1, meaning that the inside surface of the molten tube is drawn the same amount as the outside surface.

$$DRB = \frac{(D_d / D_t)}{(D_m / D_b)}$$

Draw Ratio Balance

Calibration for tubing

D_t (mm) (OD)	8	10	12	16	23	30	44
D_b (mm) (ID)	6	8	10	13	20	26	39
D_d (mm)	9.8 to 15	12.2 to 18.7	14.7 to 22.4	19.6 to 29.9	28.2 to 43	36.7 to 56.1	53.9 to 82.3
D_m min (mm)	7.3 to 11.2	9.8 to 15	12.2 to 18.7	15.9 to 24.3	24.5 to 37.4	31.8 to 48.6	47.8 to 73
DDR	1.5 to 3.5						
DRB	0.95 to 1.05						

SIZING DIE FOR TUBING EXTRUSION

It is recommended that a tubular sleeve sizing die made from brass is used, with holes allowing the surrounding vacuum to act on the extruded tube. The diameter of the holes is advised to be around 1 mm and the distance between each hole around 5 mm. One can also use a sizing die with plates; the distance between the plates should be 1 mm maximum, and the total length is advised to be 50 mm. The diameter of the die should be between 3 and 15% oversized to compensate for shrinkage of the tube. An annular water ring device is recommended at the entrance to the die, to allow a fine water flow that provides lubrication between the extruded polymer and the metal surface of the sizing die.

ANNULAR WATER RING & TUBULAR SIZING DIE WITH HOLES OR WITH PLATES

SHUT-DOWN AND PURGING REMARKS

No action is required for brief interruptions of up to 30 minutes. Over this limit, it is suggested that the temperature in the barrel is reduced to 150°C (300°F). Certain grades may start to increase in viscosity with extended extruder stoppage times or excessively low flow velocity. With these grades, it is important to maintain a good flow rate through the extruder and to purge with a suitable polyethylene grade (usually HDPE) when stopping the extruder for more than a few minutes.

REGROUND MATERIAL

Using regrind is not recommended for extrusion applications.

D_d = Internal diameter of extrusion die
D_m = External diameter of pin (mandrel)
D_t = External diameter of tube
D_b = Internal tube bore or diameter

MAIN APPLICATIONS

Grades	Name	Hose	Profile	Monofilament	Small tubing	Large tubing	Sheeting, cast film	Blown film	Film	Wire and cable	External coating	Corrugate	Optical cable	Stock shape	Mandrels
DuPont™ Zytel® Long Chain Polyamide															
Series 1000	RS LC1000	•	•	•	•	•	•		•	•			•	•	
	RS LC1010			•	•		•	•	•	•		•			•
	RS LC1200		•		•	•	•	•	•		•	•		•	•
	RS LC1201		•		•	•	•	•	•		•	•		•	•
	RS LC1600	•	•		•	•	•					•			
	RS LC1610	•	•		•	•	•					•			
	RS LC1800			•	•	•	•			•		•			
Series 2000	RS LC2600			•	•	•	•					•			
	RS LC2800	•		•	•	•	•			•		•			
Series 3000	RS LC3030			•	•					•			•		
	RS LC3060		•	•			•			•	•	•	•		
	RS LC3090	•	•			•	•	•	•		•	•		•	•
Series 4000	RS LC4601	•		•	•	•	•	•	•		•	•			
	RS LC4602	•		•	•	•	•	•	•		•	•			
Series 6000	151, 151L			•	•		•			•			•		
	153 HSL			•	•		•			•			•		
	157 HSL			•	•		•			•			•		
	158, 158L	•		•	•		•		•	•		•	•		•
	159, 159L	•	•	•	•	•	•		•	•	•	•	•	•	•
	FE310001	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	FE3734			•						•					
	LC6200, LC6210	•	•		•	•	•		•		•	•			•
	350PHS2	•	•		•	•	•		•		•	•			•
Series 7000	LC7601	•		•	•	•	•	•	•		•	•			•
	LC7602	•		•	•	•	•	•	•		•	•			•
DuPont™ Zytel® PA6 & PA66 for extrusion															
PA6	BM7300THS		•			•								•	
	BM73G15THS		•			•								•	
	FN727	•	•		•	•	•		•	•	•			•	
	ST811HS	•	•		•	•	•	•	•		•	•		•	•
	ST7301	•	•		•	•	•	•	•		•	•		•	•
PA66	101, 101L			•	•		•			•			•		
	103HSL			•	•		•			•			•		
	CFE8005HS	•	•		•	•	•	•	•		•	•		•	•
	FN714		•	•	•		•		•	•		•	•		
	FN718		•	•	•		•	•	•	•		•	•		
	BM70G20HSLX		•			•								•	
	ST801	•	•		•	•	•	•	•		•	•		•	•
	E40		•	•	•	•	•		•	•			•		
	E41HSB		•	•	•	•	•		•	•			•		
	42A, E42A, E42L			•	•	•	•		•	•		•	•		
	E50	•	•	•	•	•	•		•			•	•	•	•
	E51HSB	•	•	•	•	•	•		•			•	•	•	•
	E53	•		•	•	•	•	•	•			•	•	•	•
	70G33HSL		•			•								•	

IMPORTANT: Before any development with the above listed grades, please check the availability of the material with your DuPont representative.

TROUBLESHOOTING GUIDE FOR EXTRUSION OF DUPONT™ ZYTEL®

PROBLEMS	PROBABLE CAUSES & SUGGESTED SOLUTIONS
Unmelted or frozen particles in extrudate	▪ Barrel temperature setting too low, heater capacity too low. Recommended: 4 to 7 W/cm^2 ▪ Granules are not melting properly in screw: change temp. profile (e.g. raising rear, reducing front temperature) ▪ Compression ratio of screw too low: may be adjusted by increasing back pressure with screen pack ▪ Change screw to recommended design ▪ Inadequate screen pack: increase screen pack density ▪ Cold spots in extruder: check operation of heaters, controllers and thermocouples
Diameter variations along the extruded length	▪ Temperature cycling: check operation of controllers including setting of proportional band ▪ Variations in take-off speed: check resin drying conditions ▪ Excessive drag on sizing die: check design, reduce vacuum
Out of roundness - poor concentricity or deformed extrudate	▪ Extrudate sags before entering water bath or sizing die: reduce temperature of melt, check moisture ▪ Reduce pressure applied by haul-off, increase cooling capacity so that the tube is cold before it reaches haul-off
Surging	▪ Irregular feeding: change temperature profile, check feed throat cooling, barrel or screw wear ▪ Inadequate melt back pressure: check mesh screen pack and screw design ▪ Temperature variations: check temperature controllers, thermocouples and heater, power ▪ Slippage in haul-off or speed variations
Deformed/Folded/ Warped extrudate	▪ Adjust die centering, check DDR and DRB
Blisters/Bubbles (on surface)	▪ Resin contains volatile substances: pre-heat or dry material, reduce temperatures ▪ Check for stagnation (dead spots) in extruder or die, check operation of heaters, controllers, thermocouples ▪ Check moisture in resin
Surface roughness	▪ Die temperature too low, contamination, build-up (deposits) on die face, degradation, resin moisture ▪ Die imperfections, burrs: check surface finish of die and pin ▪ Melt fracture ("sharkskin"): reduce shear in die by reducing extrusion rate ▪ Increase die and melt temperature, increase die opening & DDR
Internal "ripples" on surface of tubing	▪ Excessive water turbulence in cooling bath ▪ Vibrations in equipment ▪ Stick-slip: reduce vacuum on sizing die, sandblast inner surface of sizing die
Pinholes, lumps tears, splits or cone breaks	▪ Contamination, excessively high DDR ▪ Temperature of extrudate too low: raise melt and / or die temperature ▪ Poor dispersion of fillers or pigments ▪ Degraded resin released from head: ensure head design is streamlined with no hold up spot

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