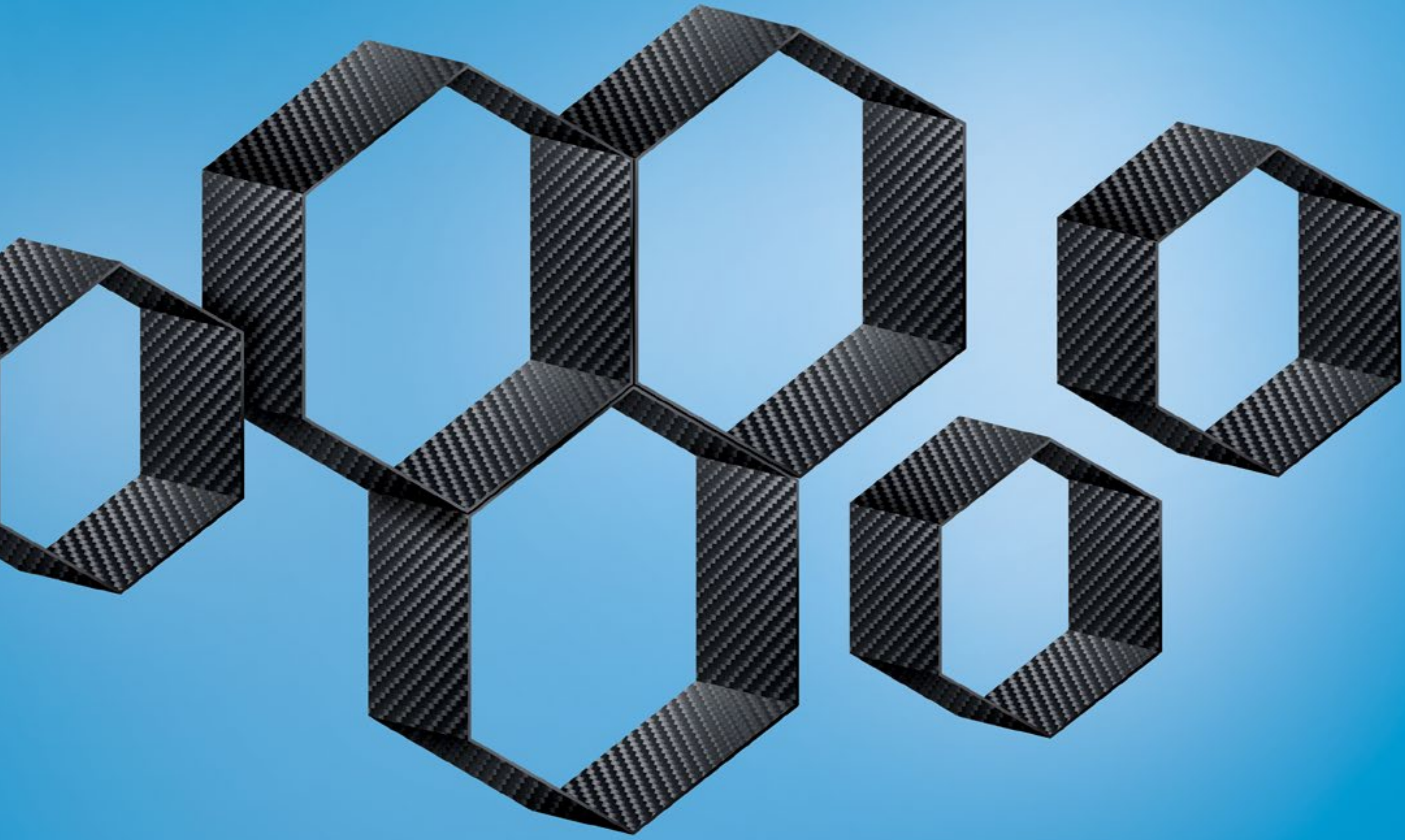
CARBON-FIBRE REINFORCED COMPOUNDS

AKROMID® ICF (PA 6, PA 6.6, PPA)
AKROTEK® ICF (Aliphatic Polyketone)
AKROLOY® ICF (PA Blend)



Think Polyamide

AKRO-PLASTIC GmbH
Member of the Feddersen Group

ICF – lightness, structure, stiffness and a competitive edge, all combined in a single material

As Henry Ford put it, “You can have any color, as long as it’s black”. The same is true for ICF products from AKRO-PLASTIC GmbH, as they also come only in black. What makes our innovative, carbon-fibre-based compounds stand out is their extreme stiffness and extremely competitive price tag.

Using tried-and-tested compounding technology from our sister company, FEDDEM GmbH & Co. KG, we offer ICF compounds based on polyamide 6 (AKROMID® B), polyamide 6.6 (AKROMID® A) PPA (AKROMID® T) and partially automatic PA 6.6 (AKROLOY® PA), as well as aliphatic polyketone (AKROTEK® PK).

Outstanding properties of this product range include:

- Good tribological properties (low-wear)
- Good electrical conductivity
- Good thermal conductivity
- Excellent stiffness and flexural stiffness
- Good flexural stress
- Low linear thermal expansion

In this brochure, you will find a selection of products we currently manufacture. Please contact our Customer Service to obtain more information.

AKROMID® ICF

Typical values for material at 23 °C	Test Specification	Test Method	Unit	A3 ICF 15 black (5056)		A3 ICF 20 black (5102)		A3 ICF 30 black (5021)		A3 ICF 40 black (5116)		A3 ICF 20 S1 black (5057)		B3 ICF 15 black (5026)		B3 ICF 20 black (5103)		B3 ICF 30 black (5119)		B3 ICF 40 black (5020)		B3 ICF 20 1 L black (5296)	
Mechanical Properties				d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.
Tensile modulus	1 mm/min	ISO 527-1/2	MPa	12,000	7,400	16,000	10,400	20,000	15,000	33,000	20,000	11,100	6,500	11,000	5,000	13,500	7,000	23,000	11,000	32,000	13,600	14,200	9,700
Yield stress/Tensile stress at break	5 mm/min	ISO 527-1/2	MPa	170	110	190	135	220	170	270	200	130	95	140	80	150	100	200	125	220	135	140	120
Elongation at break	5 mm/min	ISO 527-1/2	%	3	5	2.5	4	2	3.5	1.5	2.5	3	6	3	7	2.5	6	2	4	1.7	3	2.5	4.5
Flexural modulus	2 mm/min	ISO 178	MPa	10,400	7,000	14,000		22,000	14,000	30,000	22,000	10,000		9,000		12,000	7,000	18,000	11,300	25,000	17,000		
Flexural stress	2 mm/min	ISO 178	MPa	250	170	280		370	265	370	300	210		210		240	155	290	200	320	215		
Flexural strain at break	2 mm/min	ISO 178	%	3	5	3		2.5	3.5	1.8	2.5	3.0		3.5		3	5	2	3.5	1.8	2.5		
Charpy impact strength	23 °C	ISO 179-1/1eU	kJ/m²	45	65	50	60	55	70	60	67	50	65	55	80	55	70	55	70	60	65	50	
Charpy impact strength	-30 °C	ISO 179-1/1eU	kJ/m²	35		42		55		55				44		52		52		50			
Charpy notched impact strength	23 °C	ISO 179-1/1eA	kJ/m²	5	6	6	8	8	11	9	12			6	11	7	13	10	16	10	15	9	
Charpy notched impact strength	-30 °C	ISO 179-1/1eA	kJ/m²	4		4		6		7				4		5		7		8			
Electrical Properties																							
Surface resistivity		IEC 60093	Ohm	1.0E+5	1.0E+5	1.0E+4	1.0E+4	1.0E+4	1.0E+4	1.0E+3	1.0E+3			1.0E+5	1.0E+5	1.0E+4	1.0E+4	1.0E+3	1.0E+3	1.0E+3	1.0E+3		
Thermal Properties				d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.	
Melting point	DSC, 10 K/min	ISO 11357-1	°C	262		262		262		262		262		220		220		220		220		222	
Heat distortion temperature, HDT/A	1.8 MPa	ISO 75-1/2	°C	245		250		254		255		240		200		202		210		210			
Coefficient of linear thermal expansion (CLTE), flow	20 °C - 80 °C	ISO 11359-1/2	1.0E-4/K																	0.17			
Coefficient of linear thermal expansion (CLTE), transverse	20 °C - 80 °C	ISO 11359-1/2	1.0E-4/K																	0.73			
Thermal conductivity		DIN 52612	W/mK			0.34		0.42		0.47				0.31						0.41			
Flammability																							
Flammability acc.UL 94	1.6 mm	UL 94	Class	HB		HB		HB		HB		HB		HB		HB		HB		HB			
Rate acc. FMVSS 302 (<100 mm/min)	>1 mm thickness	FMVSS 302																+					
General Properties																							
Density	23 °C	ISO 1183	g/cm³	1.2		1.23		1.28		1.34		1.18		1.19		1.22		1.28		1.31		1.15	
Content reinforcement		ISO 1172	%	15		20		30		40		20		15		20		30		40		20	
Moisture absorption	70 °C/62 % r.h.	ISO 1110	%					1.9		1.5		1.9		2.7		2.6		2.1		1.9			
Processing																							
Flowability	Flowspiral[1]	AKRO	mm	500						360				360						240			
Processing shrinkage, flow		ISO 294-4	%	0.4		0.25		0.22		0.19				0.1		0.1		0.15		0.1		0.25	
Processing shrinkage, transverse		ISO 294-4	%	0.8		0.8		0.73		0.67				0.7		0.6		0.53		0.5		0.67	

[1] = AKROMID® A: mould temperature: 100 °C, melt temperature: 300 °C, injection pressure: 730 bar, cross section of flow spiral: 7 mm x 2 mm
AKROMID® B: mould temperature: 80 °C, melt temperature: 270 °C, injection pressure: 750 bar, cross section of flow spiral: 7 mm x 2 mm
+ = passed

“cond.” test values = conditioned, measured on test specimens stored according to ISO 1110
“d.a.m.” = dry as moulded test values = residual moisture content < 0.10 %

AKROMID® ICF

AKROTEK® ICF + AKROLOY® ICF

Typical values for material at 23 °C	Test Specification	Test Method	Unit	B28 ICF 20 RM-D GIT black (5517)		C3 ICF 30 5 XTC black (5473)		T1 ICF 10 black (5146)		T1 ICF 20 black (5147)		T1 ICF 30 black (5148)		PK-VM ICF 30 black (5403)		PA ICF 10 black (5267)		PA ICF 20 black (5268)		PA ICF 30 black (5269)		PA ICF 40 black (5270)	
Mechanical Properties				d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.	d.a.m.	cond.
Tensile modulus	1 mm/min	ISO 527-1/2	MPa	14,900		25,000		10,000	10,500	18,000	17,500	27,000	27,000	18,500		9,000		17,000		25,000	23,000	35,000	32,000
Yield stress/Tensile stress at break	5 mm/min	ISO 527-1/2	MPa	165		210		120	120	200	200	240	240	120		130		200		220	200	250	230
Elongation at break	5 mm/min	ISO 527-1/2	%	2.2		1.5		1.5	1.5	1.5	1.5	1.2	1.2	1.0		2		2		1.5	1.6	1.5	1.5
Flexural modulus	2 mm/min	ISO 178	MPa			21,500		10,000	9,500	17,000	16,200	25,000	24,500	21,00		7,000		13,000		21,000	21,500	35,000	
Flexural stress	2 mm/min	ISO 178	MPa			320		200	200	300	300	340	340	185		190		250		320	300	400	
Flexural strain at break	2 mm/min	ISO 178	%			2		2	2.5	2	2	1.5	1.6	1,2		4.0		2.6		2	2	1.5	
Charpy impact strength	23 °C	ISO 179-1/1eU	kJ/m²	44		45		16	20	35	30	35	38	35		25		45		50	50	50	50
Charpy impact strength	-30 °C	ISO 179-1/1eU	kJ/m²			40						33		25		22		35		40		50	
Charpy notched impact strength	23 °C	ISO 179-1/1eA	kJ/m²			7		3	3	4	4	5	5	7.5		3		6		7	7	8	
Charpy notched impact strength	-30 °C	ISO 179-1/1eA	kJ/m²			6						5		5.5		3		5		6		7	
Electrical Properties																							
Surface resistivity		IEC 60093	Ohm					1.0E+10	1.0E+10	1.0E+5	1.0E+5	1.0E+4	1.0E+4					1.0E+5	1.0E+5	1.0E+4	1.0E+4	1.0E+4	1.0E+4
Thermal Properties				d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.		d.a.m.	
Melting point	DSC, 10 K/min	ISO 11357-1	°C			260		313		313		313		220		255		255		255		255	
Heat distortion temperature, HDT/A	1.8 MPa	ISO 75-1/2	°C									258				163		223		230		235	
Coefficient of linear thermal expansion (CLTE), flow	20 °C - 80 °C	ISO 11359-1/2	1.0E-4/K																				
Coefficient of linear thermal expansion (CLTE), transverse	20 °C - 80 °C	ISO 11359-1/2	1.0E-4/K																				
Thermal conductivity		DIN 52612	W/mK																				
Flammability																							
Flammability acc.UL 94	1.6 mm	UL 94	Class					HB		HB		HB				HB		HB		HB		HB	
Rate acc. FMVSS 302 (<100 mm/min)	>1 mm thickness	FMVSS 302														+		+		+		+	
General Properties																							
Density	23 °C	ISO 1183	g/cm³			1.28		1.19		1.25		1.34		1.32		1.19		1.23		1.29		1.35	
Content reinforcement		ISO 1172	%	20		30		10		20		30		30		10		20		30		40	
Moisture absorption	70 °C/62 % r.h.	ISO 1110	%					1.62		1.45		1.1								1.6		1.3	
Processing																							
Flowability	Flowspiral[1]	AKRO	mm							400								440				300	
Processing shrinkage, flow		ISO 294-4	%					0.5		0.22		0.1						0.2		0.15		0.28	
Processing shrinkage, transverse		ISO 294-4	%					0.7		0.64		0.6						0.6		0.49		0.42	

[1] = AKROMID® A: mould temperature: 100 °C, melt temperature: 300 °C, injection pressure: 730 bar, cross section of flow spiral: 7 mm x 2 mm
AKROMID® B: mould temperature: 80 °C, melt temperature: 270 °C, injection pressure: 750 bar, cross section of flow spiral: 7 mm x 2 mm
\+ = passed

"cond." test values = conditioned, measured on test specimens stored according to ISO 1110
"d.a.m." = dry as moulded test values = residual moisture content < 0.10 %

Product characterisation

Production process for ICF components (Fig. 1)

Carbon-fibre remnants

↓

Blackbox

Conditioning of fabric remnants

↓

Compounding

↓

ICF pellets

↓

ICF component

As the saying goes in many industries today: “Environmental and competition pressure lead to innovation and with it particularly in the automotive industry, lightweight design”. When this pressure is intense then the possibilities for constructing parts with lower weight really present themselves. Truly lightweight, innovative designs are created only when there’s no other path to follow. The aviation industry was a pioneer in the area of lightweight construction, because weight has such an important influence on fuel consumption here more than anywhere else. In December 2008, the Council and Parliament of the European Union reached an agreement on a regulation for reducing CO_2 emissions in new passenger cars. The central focus of this regulation is to reduce CO_2 emissions to 95 g/km on average by 2020. This has sparked real competition in lightweight construction. OEMs and their suppliers invest significant sums to implement new ideas, as well as ideas that have yet to be realised, in lightweight design for large-scale production. Thus several years ago, BMW decided to take a revolutionary new approach by building an entire passenger cell out of carbon-fibre-reinforced plastic.

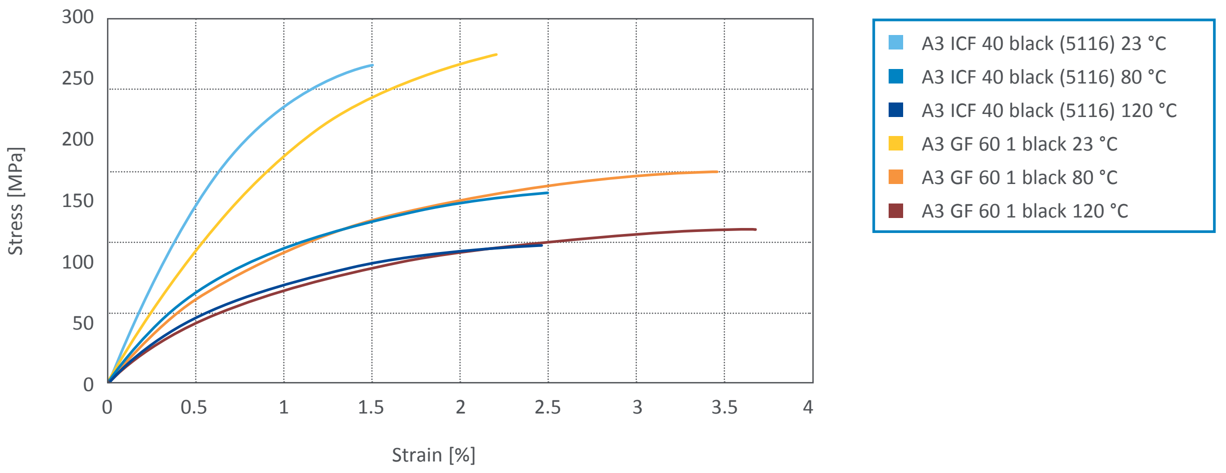
With all production processes come rather substantial quantities of waste. These can be divided into two categories: dry fibre remnants, which have never come into contact with a polymer matrix material, and wet waste material. The wet waste contains cured resin systems and can only be recycled at great cost.

The dry fibre fabrics can be recycled in various ways. Initial efforts focussed on using cut-to-length fabrics for smaller applications and impregnating them again with resins. Such manual handling of the fabrics, however, proved to be extremely cost-intensive and prone to error, and remnant cuts did not always match the geometries of new components. Thus the need arose for new solutions.

AKRO-PLASTIC has developed new ways to incorporate dry, conditioned carbon-fibre fabrics into a polymer melt in a manner which enhances the added value. This involves shredding the fabrics in a multiple-step process in such a way that they can be gravimetrically dosed on an extruder, like conventional cut-carbon fibres. The biggest obstacle in this process is a powder binder applied to the fabric. The powder binder is used to superimpose several layers of the carbon-fibre fabrics and prevent slippage in subsequent processes. An important step during the conditioning of the fibres is the dosing of the fabrics, which can only be ensured with precise temperature control.

The synchronous twin-screw extruder used at FEDDEM GmbH & Co. KG has been equipped with a newly developed side feeder. Depending on the polymer, this side feeder is capable of gently delivering up to 50 % carbon fibre content to the conditioned polymer melts. A further critical step when incorporating the prepared carbon fibres is the proper electrical encapsulation of the system technology and suitable extraction of the dosing. Otherwise, the high conductivity of carbon fibres will relatively quickly result in the destruction of the contaminated electrical components.

Stress/strain curves at temperature (Fig. 2)



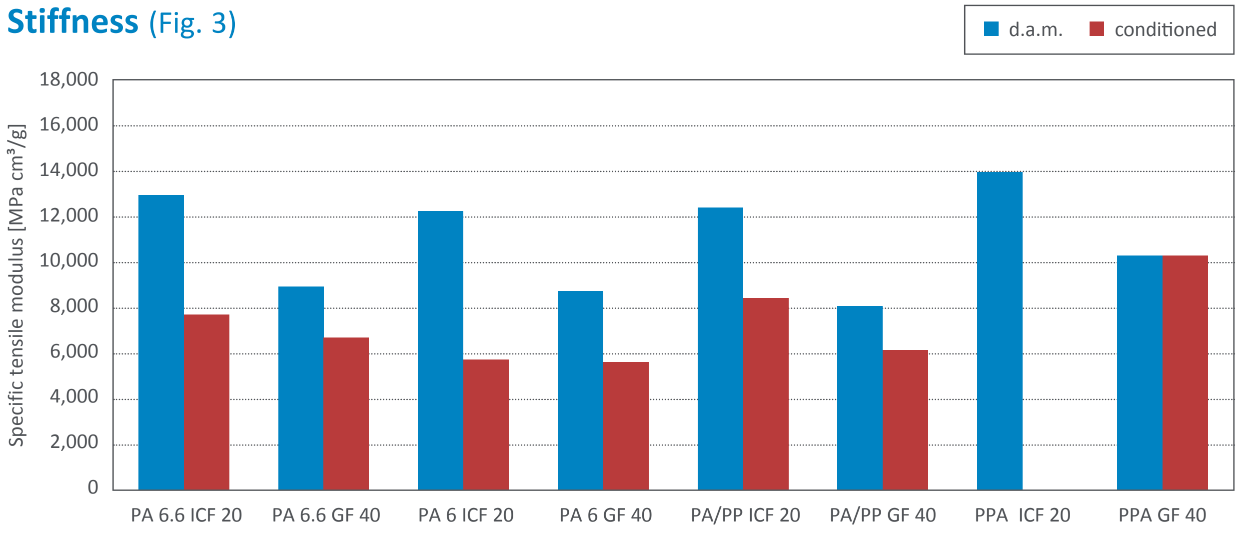
Tensile testing shows that even at higher temperatures, approximately the same strengths can be achieved with lighter ICF compounds from AKRO-PLASTIC than with significantly higher glass-fibre reinforcement. The elongation at break for carbon-fibre-reinforced compounds, however, is slightly less than for compounds with glass-fibre reinforcement – see Fig. 2.

Compared with glass fibres, the use of carbon fibres gives rise to an extreme increase in stiffness in thermoplastic compounds. This becomes clear when looking at the specific tensile modulus, that is, the tensile modulus divided by density. The ICF compounds from AKRO-PLASTIC dominate, particularly when freshly moulded. But even for conditioned compounds, the specific tensile modulus for all compounds is higher than that of a glass-fibre-reinforced alternative compound – see Fig. 3.

The AKROMID® Lite compounds do particularly well in this comparison. In this respect, the specific stiffness of a conditioned AKROMID® B3 ICF 20 1 L is approximately as high as that of a freshly moulded AKROMID® B3 GF 40 1 L.

This means that given identical geometry, components can be realised in practical applications with comparable or even greater stiffness and lower weight. For dynamically loaded structural components, the part design can be adapted based on the gain in stiffness, thereby adding to the weight savings.

Stiffness (Fig. 3)



Product characterisation

Comparison of GF vs. ICF clutch pedal (Table 1)

Properties	**Test Method**	**Unit**	**B3 GF 30 1 GIT black (4599)**	**B3 ICF 15 black (5026)**
Compound density	ISO 1183	g/cm³	1.36	1.18
Component stiffness		%	100	125
Component breaking force		N	990 +/- 40	1,100 +/- 15
Component weight		g	319	291

Called “ICF”, our new carbon-fibre-reinforced type series based on PA 6, PA 6.6, PK, PPA and partially aromatic PA 6.6 (AKROLOY® PA) combines high strength with lower density at an attractive price. The compounds are finished with a carbon fibre content of 10 % to 40 %. These materials – AKROMID® B3 ICF 40, a PA6-based compound, for instance – achieve a tensile modulus of 32,000 MPa and a flexural strength of 320 MPa, with 1.8 % elongation at break. AKROMID® A3 ICF 40, a PA 6.6-based compound, even achieves 33,000 MPa with a flexural strength of 370 MPa.

The objective of the new product line is to drastically reduce the weight of high-strength components. And for the first time, the cost now closely approximates that of glass-fibre compounds, eliminating any economic factors preventing substitution. The fact that a clutch pedal (see Fig. 4) can be manufactured in such a sensitive process as the water-injection process attests to the high quality of this newly created product line. In partnership with Engel, PME Fluidtec and Moldetipo, we were able to reduce the weight of the component by 10 % whilst achieving improved mechanical values – see Table 1.

The advantage of carbon-fibre-reinforced compounds can be put to use in many other applications as well, particularly in supporting components. In applications such as centre consoles, activated charcoal filters and brackets for control units, further advantages of carbon fibre could also be of benefit. These include: electrical shielding, favorable thermal conductivity and a lower thermal expansion coefficient.

Polyamides demonstrate slightly stronger differences between dry and conditioned stiffnesses, depending on the polymer matrix used. The PA/PP blend (AKROMID® B3 ICF 20 1 L black (5296)), by contrast, exhibits a particularly interesting property profile following water absorption. This blend is a compound in which a modified polypropylene is grafted onto the polyamide as a side chain. The stiffness exceeds that of a conditioned polyamide with 40 % fibre content, and at 1.15 g/cm³, the density is 21 % lower and thus precisely on par with unfilled polyamides. And the stiffness of the PA/PP ICF 20 (120 MPa) is nearly at the same level.

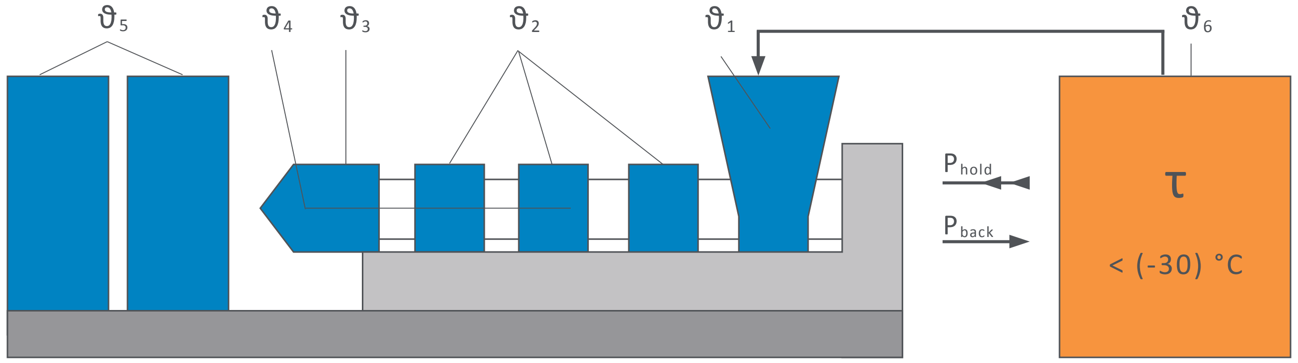
Figure 4: Wall thickness distribution, clutch pedal made of AKROMID® B3 ICF 15 black (5026)

Processing recommendations

Our ICF products can be processed on commercially available injection moulding machines with standard screws according to the recommendations of the machine manufacturer. Please refer to the table below for our recommended machine, mould and dryer settings (see diagram).

All ICF types have significantly higher thermal conductivity compared with glass-fibre-reinforced types. Components can therefore typically be demoulded with shorter cycle times.

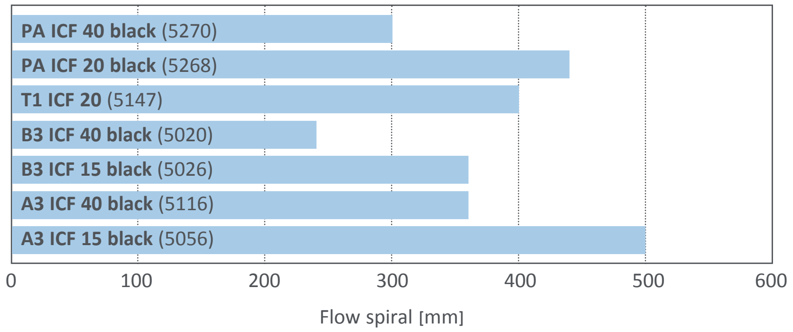
To improve weld-line strength, we recommend that mould-wall temperatures are kept as high as possible, with adequate holding pressure times. In the component design, and with carbon-fibre-reinforced components in particular, transitions and edges should be given large radii to prevent concentrations of stress in these areas.



		AKROMID® A	**AKROMID® B**	**AKROMID® T**	**AKROMID® C**	**AKROTEK® PK**	**AKROLOY® PA**
Flange	ϑ_1	40 – 80	40 – 80	70 – 100	40 – 80	40 – 80	60 – 80
Sector 1 – Sector 4	ϑ_2	265 – 310	250 – 300	320 – 350	250 – 300	210 – 250	265 – 310
Nozzle	ϑ_3	280 – 310	270 – 280	320 – 330	280 – 300	230 – 250	290 – 310
Meld temperature	ϑ_4	280 – 300	270 – 290	330 – 345	280 – 300	230 – 250	290 – 320
Mould temperature	ϑ_5	90 – 130	70 – 130	135 – 160	80 – 130	60 – 130	80 – 140
Drying	ϑ_6	2 – 4	2 – 4	2 – 4	2 – 4	2 – 4	2 – 4
Holding pressure, spec.	P_{hold}	300 – 800	300 – 800	300 – 800	300 – 800	300 – 800	300 – 800
Back pressure, spec.	P_{back}	50 – 150	50 – 150	50 – 150	50 – 150	50 – 150	50 – 150

The specified values are for reference values. For increasing filling contents the higher values should be used.
For drying, we recommend using only dry air or a vacuum dryer. Processing moisture levels between 0.05 and 0.1 % are recommended.
It is recommended to use opened bags completely.
Material processed from silo or boxes requires a minimum drying time of 4 h.

Flow length



AKROMID® A: mould temperature: 100 °C, melt temperature: 300 °C, injection pressure: 730 bar, cross section of flow spiral: 7 mm x 2 mm

AKROMID® B: mould temperature: 80 °C, melt temperature: 270 °C, injection pressure: 750 bar, cross section of flow spiral: 7 mm x 2 mm

AKROMID® T: mould temperature: 140 °C, melt temperature: 340 °C, injection pressure: 770 bar, cross section of flow spiral: 7 mm x 2 mm

AKROLOY® PA: mould temperature: 100 °C, melt temperature: 290 °C, injection pressure: 730 bar, cross section of flow spiral: 7 mm x 2 mm

Applications

Currently, a large number of potential applications will be tested. The focus is on components that require high stiffness and are installed in black. Components which are installed above the centre of gravity of the vehicle, it is particularly interesting for the vehicle manufacturer as the weight loss in this case also has a positive effect on the driving dynamics.

Figure 6: Screw made of AKROMID® T1 ICF 30 black (5148)

Screws made of AKROMID® T1 ICF 30 black (see Fig. 6) provide maximum stiffness combined with excellent chemical resistance and low creep. Screws manufactured in this way are approximately 80 % lighter than standard metal screws with identical joint integrity of the bolted plastic components.

Figure 7: Centre console made of AKROMID® A3 ICF 10 black (5117)

The centre console turned out to be an extremely interesting application – see Fig. 7. Made of PA 6.6 GF 30, this console weighed 1,680 grams. Using a 10 % ICF reinforced PA 6.6 (AKROMID® A3 ICF 10 black (5117)), it was possible to reduce the weight to 1,460 grams, with comparable stiffnesses.

Applications

Industry
- Yarn guides
- Pump slides
- Gears
- Cams
- Connecting rods
- Screws
- Valves
- Connectors

Automotive
- Vacuum pumps
- Steering modules
- Clutch pedals
- Centre console
- Drive train
- Sliding roof gate
- Fan wheels (ex protection)
- Shift gates
- Sensor housing
- Adjustment levers
- Bearing blocks
- Fuel filler necks
- Mirror housings
- Blades
- Module racks

Aviation
- Structural elements
- Luggage bins

Outlook

New blowing agent systems result in weight reduction in engineering plastics, with optimal retention of the mechanical properties and surface qualities. These blowing agent masterbatches combine the advantages of dust-free, safe handling whilst providing nucleating agents and additives which can enable in-process realisation of an optimally fine-tuned product.

In process control there are two different approaches, which are compared in Table 2 using dumbbell specimens in a 20 % carbon-fibre-reinforced (PA + PP) blend, loaded with 3.5 % masterbatch AF-Complex® PE 990310 TM. The respective compound, loaded with blowing agent and produced in a standard process, serves as the zero value. Moisture absorption influences the variants thus foamed to the same degree as the non-foamed variants.

Full shot: The component is filled completely without holding pressure. A weight reduction of 4 % compared with the standard process is realised with this variant. The mechanical properties, however, remain nearly identical. The blowing agent has a flow-enhancing effect and reduces weight only to a moderate degree, but the component surface is just as good as that achieved in the standard process, and the component is virtually free of deformation.

Short shot: The component is nearly completely filled, but without compressing the melt. This variant is also produced without holding pressure and achieves a high degree of foaming and thus a weight reduction of 13 % compared with the zero value. The tensile modulus is reduced by 15 % – approximately the same amount by which the weight was reduced.

Figure 8: Foam structure with good and poor nucleation

Comparison of standard process with and without blowing agent for short shot and full shot (Table 2)

Properties	Unit	AKROMID® B3 ICF 20 1 L	AKROMID® B3 ICF 20 1 L	AKROMID® B3 ICF 20 1 L
Shot method		**Zero value**	**Short shot**	**Full shot**
Holding pressure		with holding pressure	without holding pressure	without holding pressure
Part fill			Part fill	
Blowing agent	%	3.5 AF-Complex® TM		
Tensile modulus	MPa	12,510 [100 %]	10,660 [85 %]	12,200 [97 %]
Flexural module	MPa	12,100 [100 %]	12,240 [101 %]	12,260 [101 %]
Flexural strength	MPa	202 [100 %]	185 [92 %]	198 [98 %]
Flexural strain	%	2.7	2.4	2.6
Weight reduction	%		13	4
Density	g/cm³	1.10	0.96	1.06

We will be pleased to meet you!

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