

Guideline for Carbon Fiber reinforced ICF Compounds

Introduction to ICF compounds

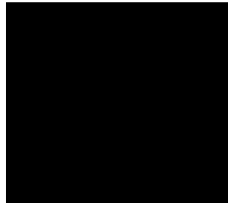
ICF compounds are made from resin-free refined cut-offs from Carbon Fiber fabrics, making them both resource-efficient and economical while bringing the same performance as regular Carbon Fiber compounds.

ICF - carbon fiber reinforced compounds offer enhanced properties compared to both neat resins and glass fiber reinforced resins. These properties include high tensile strength and modulus as well as flex strength and modulus. Its low specific gravity makes it an excellent material choice for weight reduction in metal to plastic conversions.

Structural applications such as center consoles or brackets for control units can also benefit from carbon fiber properties. These include electrical shielding, good thermal conductivity and low coefficient of thermal expansion.



Carbon fiber cut-offs



*Blackbox
Preparation of the cut offs*



Compounding



ICF-Pellets



ICF- injection molded part

General Considerations

When designing parts for carbon fiber reinforced ICF compounds rheological as well as mechanical properties need to be considered. As a carbon fiber reinforced ICF part is filled, the fibers will orient in the direction of flow. The fiber orientation will have an effect on shrinkage (see next slide for more information). The orientation of fibers also causes anisotropic ultimate strength of the part.

The performance of parts molded from carbon fiber reinforced ICF compounds can also be affected by weld lines. Weld lines are also covered in detail in the “Weld Line Strength” section. It is also important for designers to consider weld line locations and find ways to limit the number of weld lines when designing for carbon fiber reinforced ICF compounds. If weld lines cannot be avoided, designers should adjust the part geometry to move weld lines away from critical areas or utilize processing techniques to mitigate areas of concern.

Carbon fiber reinforced ICF compounds may be notch sensitive. To prevent fracture due to stress concentrations in the part, it is very important to provide ample fillets at intersections. Eliminating sharp corners will reduce stress concentrations. Parts should also be designed to introduce any metal threaded inserts as over molded components. Self-tapping screws will increase stress on the part and have been found to lead to part failures.

Shrinkage

When the melt cools, the fibers which are aligned in the direction of flow inhibit shrinkage in this direction, but not in the transverse direction, resulting in non-uniform shrinkage. Anisotropic shrinkage is a major cause of part warpage in reinforced thermoplastics and should be given special consideration during the design phase.

The shrinkage for carbon fiber reinforced ICF compounds may range from 0.1% to 0.8%. It is extremely important to consider this low shrinkage when choosing draft angles. Sufficient draft angle will allow for easy removal of parts from the mold, see section “Mold Design – Ejection”.

The low shrinkage may also pose problems when determining what side of the mold a part will stay during the mold opening phase of the injection cycle. For example, a part will generally shrink tight enough around a standing core on the moveable side of a mold to keep it on that side when the mold opens. When using a resin that has little to no shrinkage, like carbon fiber reinforced ICF compounds, the shrinkage around a standing core may not create enough gripping force to keep the molded part on the correct half of the mold. If possible, it is beneficial to sample ICF compounds in similar molds.

Weld Line Strength

Weld lines form when flow fronts come together during the filling stage of molding. Depending on process conditions, weld line strength can vary significantly. Carbon fiber reinforced ICF compounds are particularly prone to weakness at weld lines within the part because when the flow fronts reconnect, fibers are not able to cross the weld line. In these locations, the part strength may be as low as unfilled ICF resin. Awareness of weld line location is advisable, and avoidance in critical areas is crucial. If the part is not designed properly, weak weld lines can result in premature part failure.

If weld lines cannot be avoided, designers should adjust the part geometry to move weld lines away from critical areas or utilize processing techniques to mitigate areas of concern. One of such techniques is cascade molding (also called cascade injection or cascade fill) which is a form of sequential valve gating. In certain hot runner injection molding applications, optimum part fill is achieved opening each individual valve gate nozzle in a staggered sequence, creating a cascade progression of the melt's flow front through the mold cavity, from one gate to the next. This method is used primarily to create high quality plastic parts without weld lines. It can also be used to reduce clamp tonnage for large surface parts.

In order to study the influencing processing parameters on the weld line strength, a trials has been conducted.

Examination of weld line strength

Trials have been conducted with AKROMID® A3 ICF 40 (5116). A tensile bar that forms a welding line in the middle was injected with different parameters and the resulting mechanical properties were evaluated.

Four processing parameters were varied on two stages, a high level (+1) and a low level (-1). This resembles a full factorial design of experiment resulting in $2^4 = 16$ trial points.

Varied process parameters IMM		
mold temp.	140°C	+1
	60°C	-1
Melt temp.	310°C	+1
	280°C	-1
Injection speed	100 cm³/s	+1
	10 cm³/s	-1
Holding pressure	1600 bar	+1
	800 bar	-1

Fixed parameters	
Holding pressure time	15 s
Back pressure	50 bar
Dosage volume	46 cm³
Dekompression	5 cm³
Dosing speed	12 m/min
Residual cooling time	25 s
Switchover volume	9 cm³
material moisture content	0,07%

Weld Line Strength of AKROMID A3 ICF 40 (5116) - Results

Trial	Varried Parameters				Results		
	Mold temp.	Melt temp.	Injection Speed	Holding pressure	Weld Line Strength [MPa]	Elongation at break [%]	Young's Modulus [MPa]
1	-1	-1	-1	-1	54,1	0,3	17362
2	-1	-1	-1	+1	54,2	0,3	17455
3	-1	-1	+1	-1	42	0,2	-
4	-1	-1	+1	+1	50,6	0,3	18523
5	-1	+1	-1	-1	71,4	0,4	17775
6	-1	+1	-1	+1	76,8	0,5	18247
7	-1	+1	+1	-1	60,1	0,3	21187
8	-1	+1	+1	+1	76,6	0,4	19117
9	+1	-1	-1	-1	61	0,4	15152
10	+1	-1	-1	+1	65,4	0,4	15587
11	+1	-1	+1	-1	49,7	0,3	18538
12	+1	-1	+1	+1	58,9	0,3	19237
13	+1	+1	-1	-1	69,1	0,4	19363
14	+1	+1	-1	+1	74,6	0,4	18596
15	+1	+1	+1	-1	65,8	0,3	20350
16	+1	+1	+1	+1	70,8	0,4	20148

Highest Strength at high melt temperature

Varied process parameters IMM

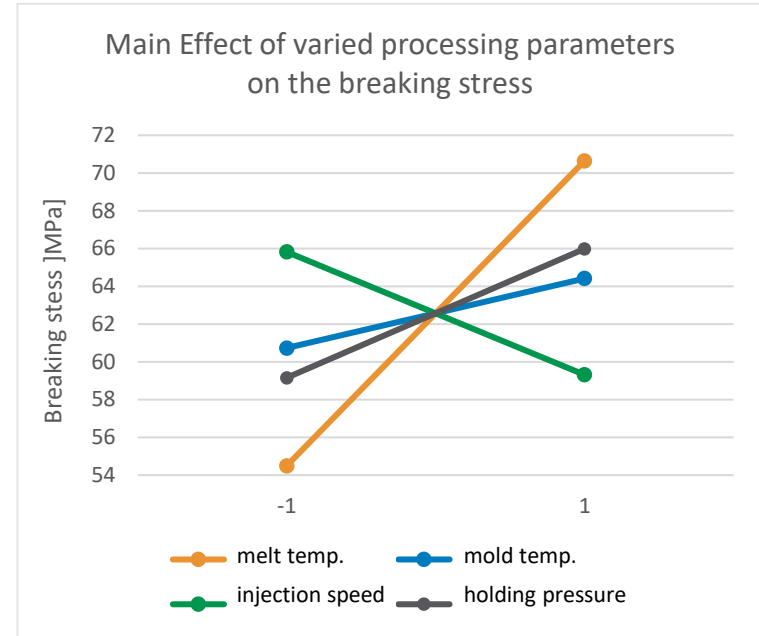
mold temp.	140°C	+1
	60°C	-1
Melt temp.	310°C	+1
	280°C	-1
Injection speed	100 cm ³ /s	+1
	10 cm ³ /s	-1
Holding pressure	1600 bar	+1
	800 bar	-1

Effects of process parameters on weld line strength

The main effect of a parameter is calculated by averaging the result (in this case breaking stress) at which the parameter was set to -1 and subtracting it from the average of breaking stress at which the parameter was set to +1.

	mold temp.	Melt temp.	Injection speed	Holding pressure
Effect	3.6875	16.1625	-6.5125	6.8375
Average -1	60.725	54.4875	65.825	59.15
Average +1	64.4125	70.65	59.3125	65.9875

The melt temperature has the greatest influence on the weld line strength. The effect of the holding pressure and the injection speed is almost the same, but the injection speed is negative (higher injection speed leads to lower weld line strength). The mold temperature has the smallest influence on the weld line strength.



Mold Design - Gating

Processing carbon fiber reinforced ICF compounds can be challenging if proper tooling design guidelines are not followed. Cycle time, internal part stress and final part strength are all affected by decisions made during the tooling design phase of your project.

Gating

The preferred gate design for ICF compounds is a direct gate. This method provides the least restriction of flow, and can be located centrally on the part, which reduces the overall flow length required to fill. Direct gates should be located at the thickest section, with their diameters twice the thickness of that section, but no greater than 12 mm in diameter. Downsides to direct gating include higher likelihood of warpage in rectangular shapes, increased probability of gate blush or sunburst effect and marks from gate removal.

Another good gate option are edge gates. Edge gates also provide fewer flow restrictions than other types of gates but are less likely to cause sunburst and help reduce warpage caused by fiber orientation. The downsides to edge gating are decreased flow lengths and potential difficulties filling larger, thin-walled parts. For optimum resin flow, the height of the gate should generally be 85-100% of the wall thickness up to 3 mm. The gate width should be two times the depth. A radius should be located at the junction of the molded part to prevent surface splay and to minimize residual stress.

Mold Design – Hot Runners

If hot manifolds are used with carbon filled materials, they must be designed with care. The residence time where the resin stays in the hot runner until it enters the cavity must be taken into consideration. If this time exceeds a particular time (dependent on the resin used, but no more than 10 minutes at highest recommended temperature) there could be degradation of the resin, resulting in poor properties.

If maximum residence time and/or temperature is exceeded, there is also the risk of carbonization of the resin due to the presence of carbon fibers. This is particularly important for shut-off nozzles, as small openings can be blocked by carbonized material.

Attention must be given to hot runner nozzle and the contact area between mold and hot runner. The contact area must be minimized to avoid freezing of the nozzle due to an unacceptable heat transfer from the nozzle tip to the mold. This is of particular importance with ICF resins. Compared to glass fiber filled resins the heat conductivity of ICF resins is much higher. To assess the performance of a particular hot runner, it is recommended to stop the process for five minutes. If a startup after five minutes is not possible due to freeze-off in the hot runner nozzle, the thermal insulation is insufficient. The contact area between mold and hot runner must be reduced. Further the location of the thermocouple should be checked. It is recommended that the location of the thermocouple is as close to the nozzle tip as possible. Also, it is important that the thermocouple is well connected to the steel of the nozzle. A separate temperature control zone with a thermocouple just for the hot runner nozzle is recommended.

Mold Design - Venting

Venting

Venting the mold cavity properly is imperative when molding carbon fiber reinforced ICF compounds. Insufficient venting will restrict plastic flow and make it more difficult to fill the mold cavity. Full perimeter venting should be used whenever possible to avoid air entrapment at the parting line.

Some fill patterns may trap gasses in areas that cannot be vented at the parting line. To relieve these gasses, vents can be machined on ejector pins, sleeve ejectors and moving cores to allow venting through the mold.

Mold Design - Cooling

Cooling

Uniform temperature control of the molding surfaces is critical for optimizing cycle time and part properties. Ample coolant channels within the mold are required to run ICF compounds. Typical channel diameters are 12mm or larger, 30-50 mm apart and 12 mm below cavity or core surfaces. Coolant channels should follow the surface of the cavity or core as closely as possible. Poorly designed cooling channels can create large temperature differences across the mold surface. This condition creates different cooling rates and results in residual stresses within the parts.

To improve the efficiency of temperature control units, it is recommended that mold makers incorporate insulating sheets between the clamping plate and the mold. During processing, it is important to monitor actual mold surface temperature along with coolant supply and return temperatures to ensure part quality and consistency.

Cooling time is the major portion of the total molding cycle. The cooling requirements depend on the part thickness and the level of filler in a compound. Carbon fiber reinforced ICF compound will cool faster than glass fiber reinforced or unfilled compounds due to the higher thermal conductivity of the carbon fibers which will lead to shorter cycle times. This has to be taken into account when designing the mold, so the additional thermal heat can be taken out of the system.

Mold Design - Ejection

Ejection

Draft should be included on all surfaces in the line of draw. The greater the draft angle, the easier it is to eject the part from the mold. Draft is particularly important for parts molded in carbon fiber reinforced ICF compounds, because they will experience little shrinkage during the mold cooling phase. It is recommended to include draft angles of 3° or more.

The use of stripper plates is the most preferred method of part ejection due to their large contact area. If knockout pins are used, it is important to use an ample amount. The pins should be designed with sufficient area to avoid compressing the resin surface and be located so that they do not induce stress in the part.

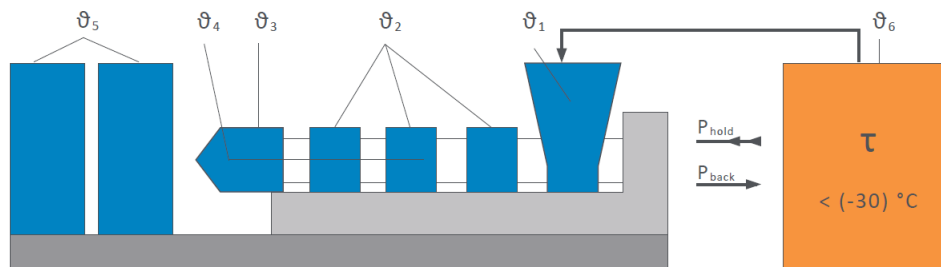
Processing Recommendations

Processing

Carbon fiber reinforced ICF compounds can be processed on commercially available injection molding machines with standard screws according to the recommendations of the machine manufacturer. Please refer to the table on the right for our recommended machine, mold and dryer settings (see diagram).

Grade-specific processing recommendations can be found via our product filter:

<https://akro-plastic.com/productfilter/>

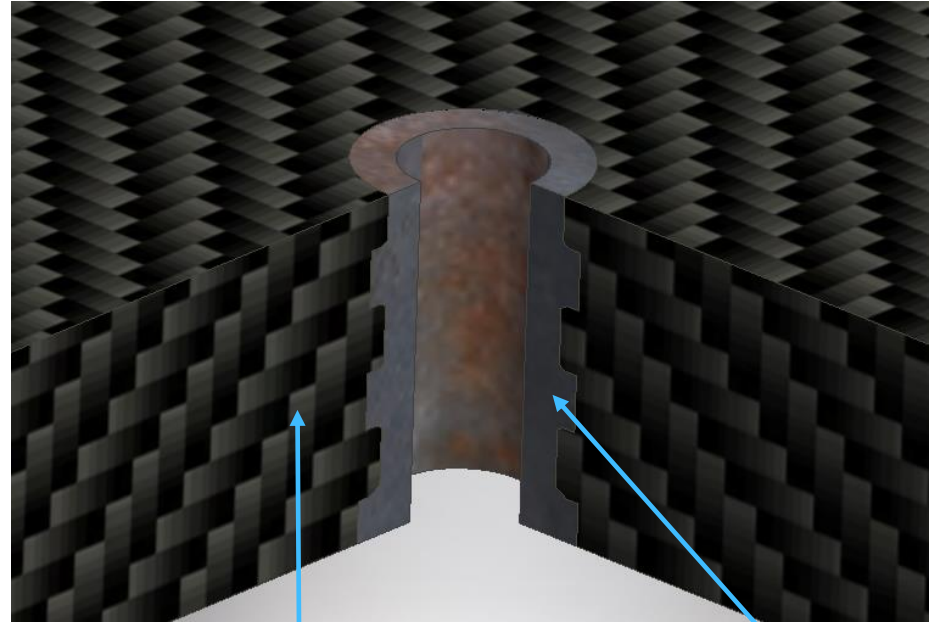


		AKROMID® A	AKROMID® B	AKROMID® T	AKROMID® C	AKROTEK® PK	AKROLOY® PA
Flange	Θ ₁	40 – 80	40 – 80	70 – 100	40 – 80	40 – 80	60 – 80
Sector 1 – Sector 4	Θ ₂	265 – 310	250 – 300	320 – 350	250 – 300	210 – 250	265 – 310
Nozzle	Θ ₃	280 – 310	270 – 280	320 – 330	280 – 300	230 – 250	290 – 310
Meld temperature	Θ 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.

Galvanic Corrosion when using Standard Metal Inserts

Often inserts made of aluminum, steel, zinc and other metals are used. When used with ICF compounds above 20 wt.-%, the inserts can corrode quickly and severely due to contact corrosion.



Carbon Fiber Reinforced Plastic
AKROLOY® PA ICF 40 (5270)

Standard Aluminium Insert

Corrosion behavior after BMW salt-spray test



The picture shows plaques which were tested using the BMW salt spray procedure for 720 hours. Standard screws were used. Composition: Screw with galvanic zinc coating, highly alloyed, black (ZNNIV SW) passivated and composed of 10-15% Nickel.

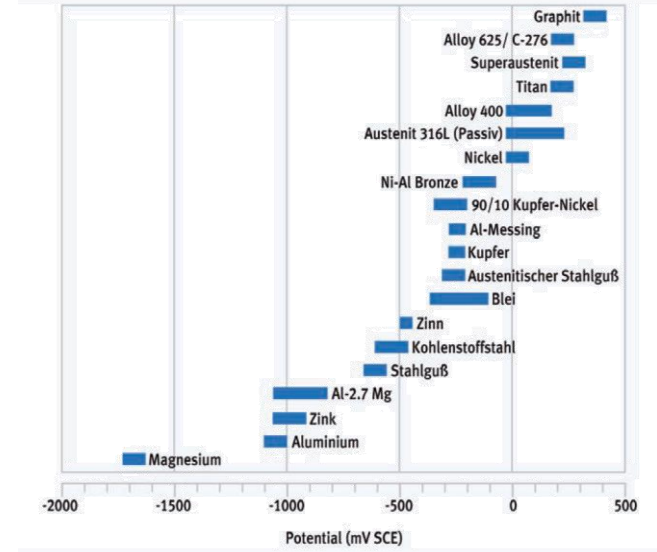
No corrosion was observed in case of AKROMID® B3 ICF 15 (5026), but significant rust was observed in grades with higher than 20% ICF reinforcement

Cause of Galvanic Corrosion

ICF carbon fiber reinforced plastics behave similar to noble metals. This is due to the presence of graphite in the carbon fiber. Screws or inserts out of steel or aluminum and others will corrode quickly when in contact with ICF compounds.

When an electrolyte like water creeps into the contact area between the metal insert and the ICF compound, it creates an electrically conductive path. Due to the electrochemical potential difference between the metal and the graphite in the carbon fiber, the metal acts as anode and the ICF compound as cathode.

The challenge when using ICF compounds is to isolate the carbon fiber from metallic elements. If the individual carbon fibers were to be embedded in a plastic matrix and electrically insulated, the contact corrosion may not appear. However, this is possible only in rare cases, therefore, the possibility still exists to block the reaction by a suitable choice of the material or to interrupt the flow of electrons between the reactants.



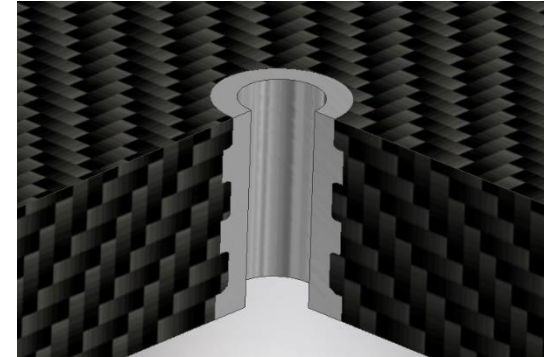
Source: WOMag 2013, Risiko der Kontaktkorrosion bei CFK-Bauteilen

Preventing Galvanic Corrosion

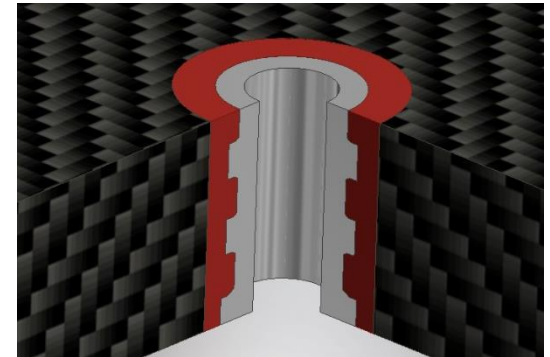
In order to prevent contact corrosion in ICF components, it is necessary to use suitable materials. The electrochemical potential difference between graphite and a metal insert should not exceed a value of 0.4 V. Suitable metals are for example titanium alloys (TiAl6V4) or stainless steel (1.4401, 1.4571 and 1.4404). However, this is a cost-intensive solution.

Another solution with high cost-saving potential: Interrupting the flow of electrons between metallic material and carbon fiber with an electrically neutral insert. As shown on the bottom cross section image, a sleeve made of a non-electrically conductive glass-fiber-reinforced plastic encloses the metallic insert, which is embedded in the ICF plastic.

Stainless Steel Insert (V4A)



Aluminum Insert + GF-reinforced Sleeve



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