for a better future

KEP

The Annealing of Plastics

R&D Center

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1. Definition

The annealing of plastics is a secondary processing procedure putting parts in the proper medium under a certain temperature between the melting temperature(Tm) and the glass transition temperature (Tg), then maintaining the temperature for a time before slowly cooling plastics down. The mediums for heating include: liquid (water, oil, ethylene glycol, etc.) or air.

The condition of plastics annealing depends on the processing method (injection, extrusion, etc.), and proper conditions have to be tailored to the purpose.

2. Effect

(1) Improves dimensional stability through acceleration of post-molding shrinkage.

Crystalline plastics such as POM, PA, and PBT have huge volume changes when they solidify due to their regular molecular orientation.

Crystalline plastics are divided into either crystalline and amorphous types, and volume reduction occurs when amorphous areas become crystalline under high using temperature. This phenomenon is called post-molding shrinkage.

The level of post-molding shrinkage depends on the processing condition like mold temperature, injection temperature, or even the thickness of the parts.

[Methods to increase dimensional stability]

① Maintaining high mold temperature during injection

High mold temperature can accelerate crystallization so that post-molding shrinkage can be minimized. Generally, if mold temperature is higher than normal-use temperature, annealing is usually unnecessary.

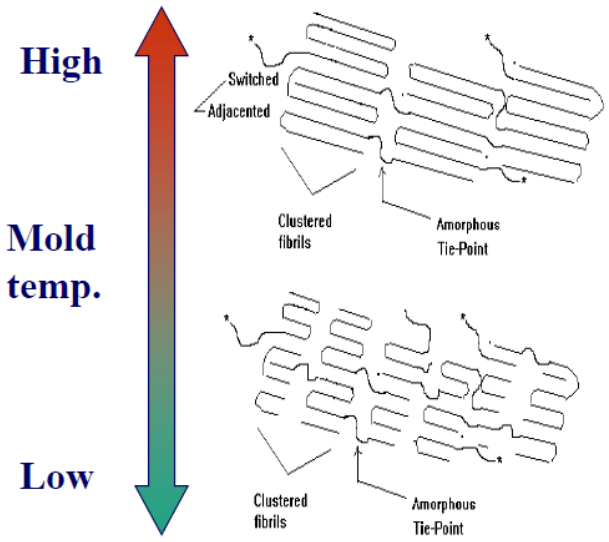
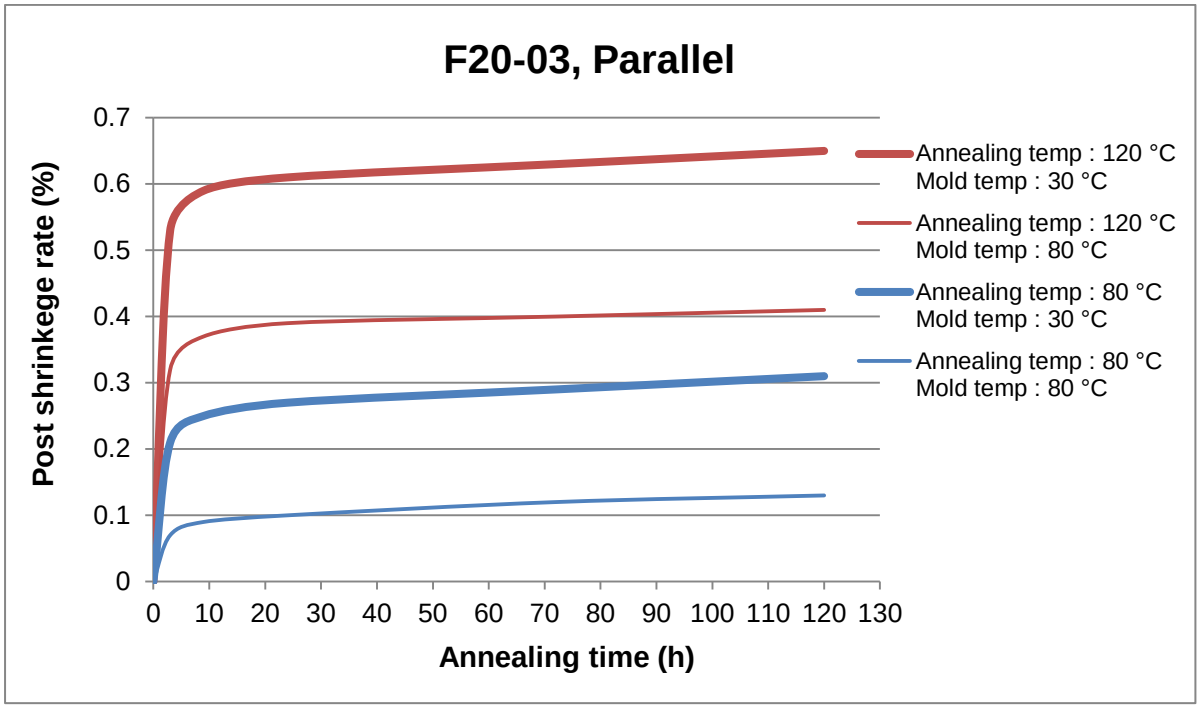


Fig. 1 Crystal structure based on mold temperature



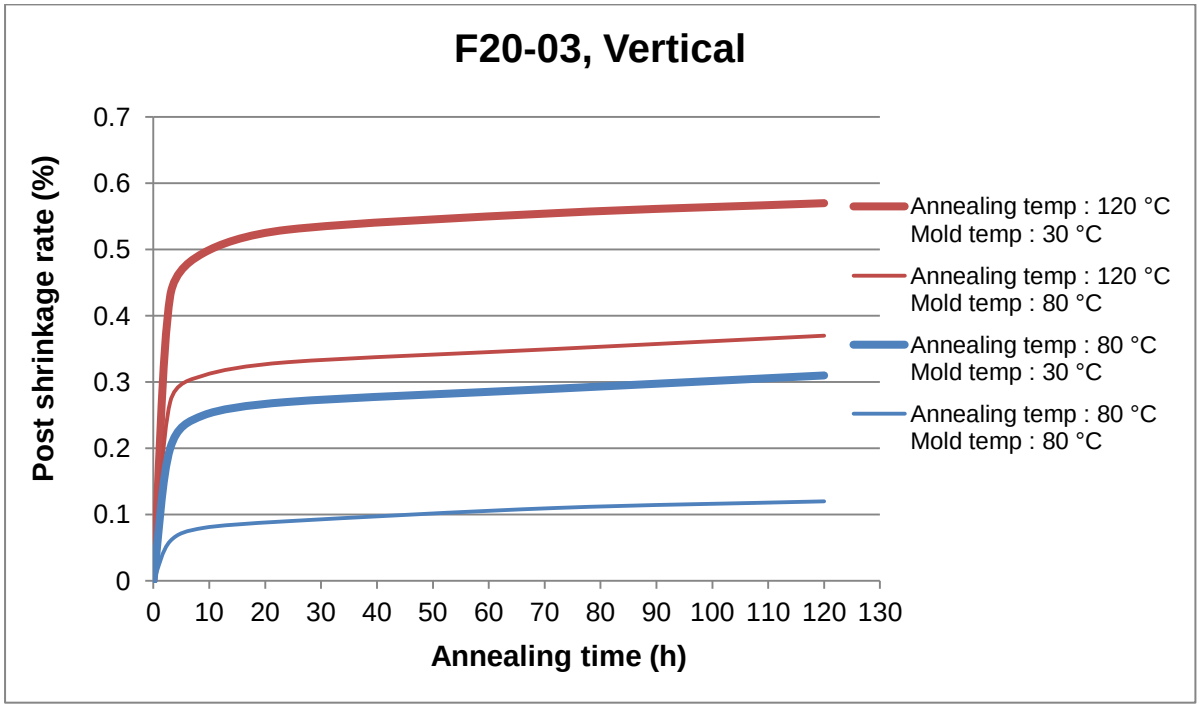


Fig. 2 Variation of post-molding shrinkage rate due to annealing time
[KEPITAL F20-03, t = 2mm]

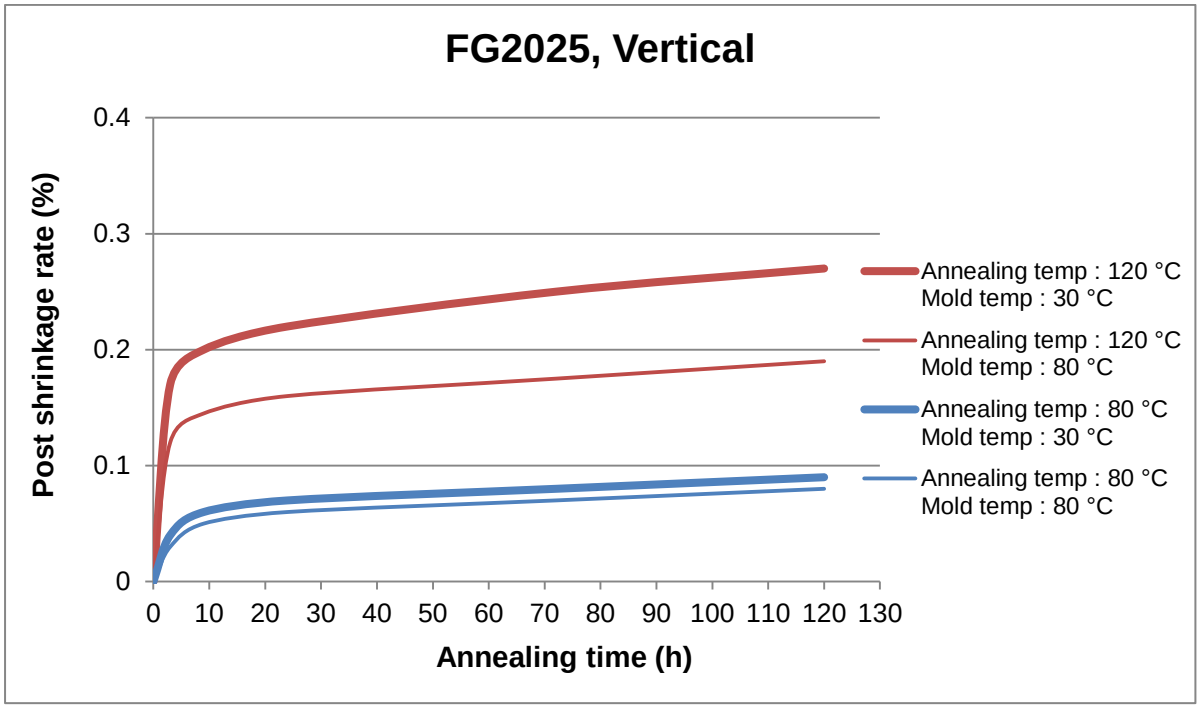


Fig. 3 Variation of post-molding shrinkage rate due to annealing time
[KEPITAL FG2025(G/F 25% reinforced, t = 2mm]

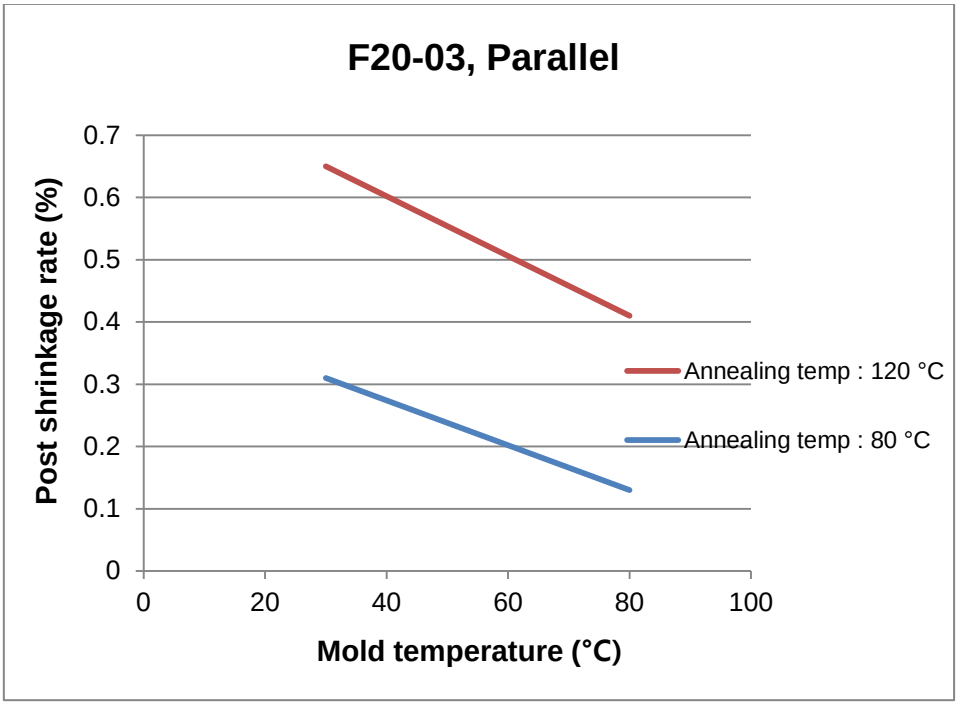


Fig. 4 Variation of post-molding shrinkage rate due to mold temperature
[KEPITAL F20-03, t = 2mm]

② Annealing

This method is to expose the part to high temperature conditions over a certain period to accelerate crystallization before use. As a result, further shrinkage during the usage period cannot occur.

(2) Improve crack resistance [Relaxing parts' internal stress]

During the injection or extrusion process, parts can incur residual stress. Stress occurs due to molecular orientation in the flow direction when the melted resin is flowing into the mold cavity or sizing die for extrusion, in addition to the shrinkage, density, and difference of crystallinity originating from uneven cooling conditions due to the partially different temperatures and the difference of cooling speed between surface and internal parts (surface cooling speed is faster) during the cooling of the resin.

Beyond that, post processing (cutting, drilling, sewing, etc.), welding, and adhesion points can incur this type of stress. As this restricts, performance of their own properties, cracks, fractures, and bending at the point of stress can easily occur. Of course, while it would reduce naturally after a while, it takes a relatively long time, so artificially adding homogeneous heat to the entire part can shorten the process.

(3) Improvement for mechanical properties

Generally plastic annealing can cause increases of density, tensile strength, flexural strength, and glass transition temperature of parts, while decreasing impact strength, elongation because of the change for plastic crystal structure, and crystallization.

(4) Improvement for heat resistance

Potential exists to improve heat resistance due to the increase of crystallization during annealing.

3. Process mechanism

In theory, annealing temperature has to be higher than the plastic's glass transition temperature (Tg), and the stress relaxation rapidly proceeds at this temperature. However, this temperature also can cause bending and torsion, and as such annealing must be performed quickly within the maximum limit of dimensional change based on the stress relaxation.

At this time, the best annealing temperature depends on the thickness, shape, volume, history of heat processing, and geometry of parts; this can be decided experimentally.

It's recommended to set the annealing temperature to 5℃ lower than the temperature

that causes the part's allowable range of maximum deformation to be reached, tested by putting part in a hot air oven or bath and raising the temperature at intervals of 3 ~ 5℃.

As this is difficult to apply realistically, Polyamide is recommended to be set to an annealing temperature around 80℃. Below this, there would be no annealing effect, while above this, water can evaporate and also runs the risk of increasing the temperature too high, and as such, the proper temperature would be 80℃.

The necessary time for annealing is selected by the part's thickness, shape, annealing medium, and is recommended to be selected by testing. Cooling speed depends on the thickness, and must be kept at a homogeneous cooling temperature between external and internal parts.

Normally, if a part's thickness is thin, the cooling speed must fast and vice versa. However, keep in mind that if the cooling speed is too fast or slow, a different cooling speed between the inside and outside can cause other residual stress.

4. Annealing medium

Annealing medium is also a factor of the annealing effect. Liquid is faster than air to deliver heat, so the process can be completed shortly.

However, it is influenced by the liquid's heat properties and so must be considered. Hot air is used widely but nylon must be treated with liquid to avoid oxidation.

Water is the best annealing medium, but the boiling point is too low so it is used together with surfactant for the purpose to increase both the boiling temperature and water absorption on the surface of the part.

Particularly in the case of nylon resin, injection parts are often to be treated with water at the 70 ~ 90℃ range for 20~40minutes. This can prevent any property or dimensional variation by moisture absorption, while also increasing the mechanical properties like the part's strength and toughness by the annealing effect.

5. Annealing method for injection parts

Injection parts' annealing temperature must be adjusted according to the usage temperature condition. Generally, it is set to 10 ~ 20℃ higher than usage temperature.

That is, if a part's usage temperature is 80℃, the proper annealing temperature is generally 90 ~ 100℃.

20℃ above usage temperature is also allowable, but if the temperature is too high, it can be incur problems like discoloration, so this needs special attention.

Although the general recommended annealing time for injection parts would be around 3 hours, parts which are thick and injected under high mold temperature can be

annealed faster. The best method is to find the proper time through testing.

6. Annealing method for extrusion parts

Thick extrusion parts as like rods and plates have different annealing conditions compared to injection parts. This is caused by large heat and time loss toward the center of the rod or plate. Generally rods and plates have to undergo a relatively higher and longer annealing process than injection parts.

6.1. Oil annealing

(1) Usage equipment : Electric heating bath

(2) Usage oil

1) Acetal resin : Purified paraffin annealing oil

2) Nylon resin

① Hydrocarbon oil or waxes

② High melting point inert mineral oil

(3) Annealing method (Rod annealing condition of acetal copolymer)

1) Oil preheated to 80℃

2) Put the extrusion part into the bath

3) Increased heat to 145 ~ 150℃

4) Maintain the fixed time 145℃ or up to 150℃

5) Slowly cool the bath to 80℃

6) Remove the extrusion part

7) Wash the part with trichloroethylene

(4) Annealing time : Depends on the thickness or diameter of the extrusion part.

6.2. Air annealing

(1) Usage equipment : Air circulation oven (Better to fill with nitrogen)

(2) Applied resin

1) Air annealing method can cause discoloration and as such is not recommended for nylon resin.

2) Air annealing method is normally recommended for PE, PP, and POM (acetal resin).

(3) Annealing method

[Table 1] Rod annealing condition of acetal copolymer

Division	Temperature	Duration (Diameter below 100mm)	Duration (Large diameter)
Heating the loaded oven	Room Temperature -> 145℃	3 h 20 min	24 h
Annealing	145℃	1000 min (16 h 40min)	48~72 h
Cooling the oven to 40 ~ 50℃	145℃ -> Room temperature	6 h	36 h
Total		26 h	108 ~ 132 h

7. Precautions

Annealing is not always necessary. Occasionally, unnecessary annealing may create dimensional issues originating from a higher shrinkage rate. In addition, annealing is not always the solution to stress.

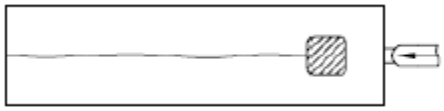
To obtain a quality product, accurate design, proper material selection and processing technique are necessary, and through this, reduction of processing errors. It is recommended to avoid annealing as post-processing, whenever possible.

(1) Precautions of G/F-reinforced products' anisotropy

Glass reinforced products can incur anisotropy. This is influenced by the part's thickness, location of gate, and shape.

(2) Do not anneal products with metal inserts

The stress in products with metal inserts forces plastics near the insert to incur too much stress under long periods of real usage temperatures, and at the same time, the size of the product is also decreased, risking cracks (especially near weld-line) around the insert.



(3) Precaution of excessive annealing

Basically, excessive annealing can cause problems like discoloration, decomposition, surface blistering, and other undesirable issues. To this end, it is recommended to find the annealing condition based on measuring the real part's dimensions.

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