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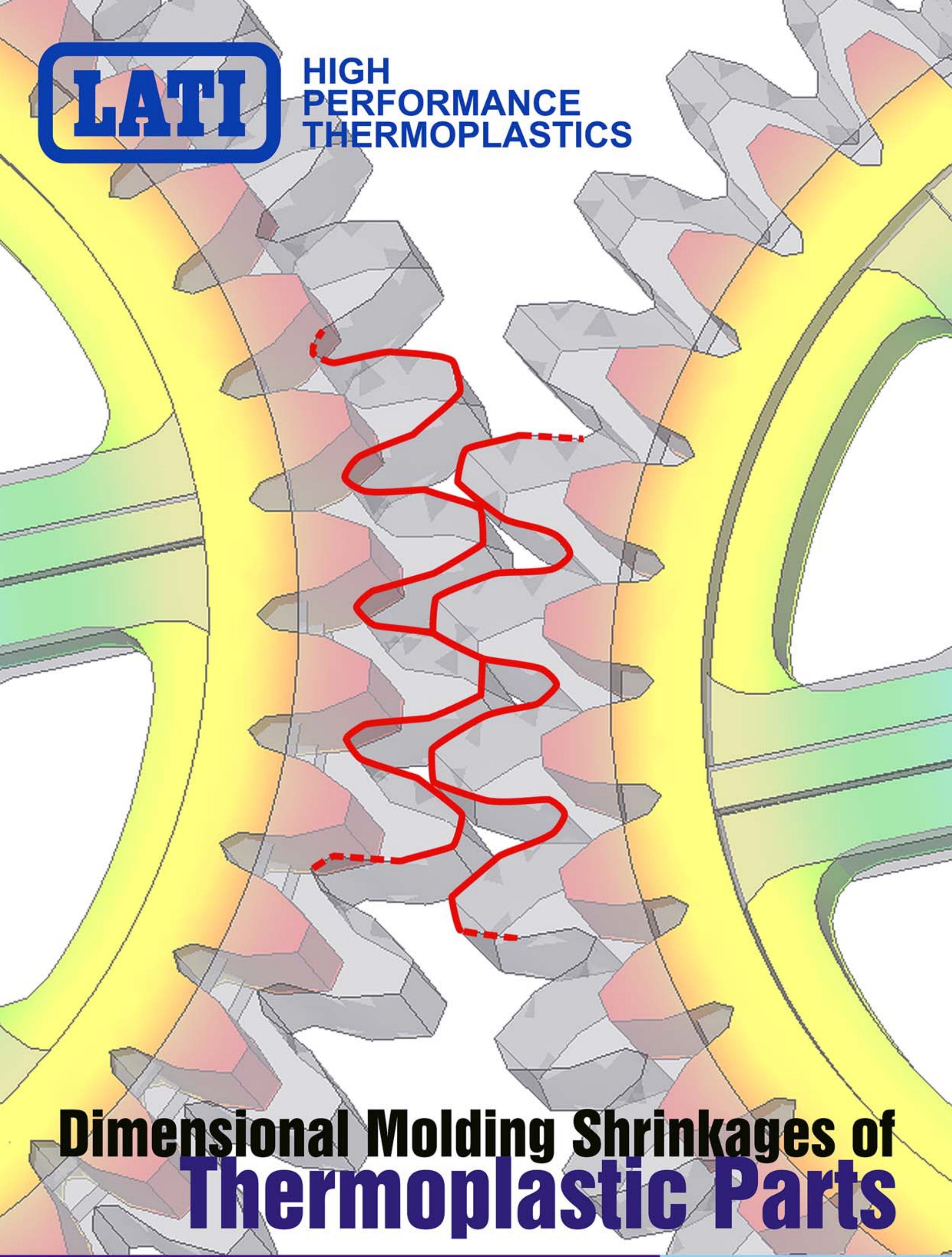

Dimensional Molding Shrinkages of Thermoplastic Parts

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INTRODUCTION

Dimensional molding shrinkage of a thermoplastic part is a typical phenomenon related to the injection molding process, caused by the volumetric shrinkage, during and after molding cycle.
For this reason, cavities, from which part is molded, have to be measured considering this important aspect, so that the part in itself has its desired measures.
However, the shrinkage entity is difficult to be evaluated because it is linked to many concomitant factors such as material features, part geometry and transformation conditions.
Purpose of this experimentation is to analyze the interaction between product-process variables and molding shrinkage property.
After introducing terms and definitions (in tabular form), the first section concerns the material typology (chemical structure and filling process); the second one analyses the influence of part geometry, underlining, above all, the part thickness; the third section, concerns transformation conditions.
Among transformation conditions, it is often important to analyze some parameters jointly. Injection molding is, in fact, a technology based on the combination of different physical properties such as temperature, speed, pressure and time.
Tests have been performed, in most cases, on semi-crystalline resins (prevalently PA66). These are very sensitive to shrinkage phenomena and to all connected parameters, unlike amorphous resins.
The exposition is supplemented, depending on the circumstances, with schedules, graphs or explanation diagrams. Otherwise curves have been obtained keeping constant transformation parameters.
Different typologies of test specimens have been used (specified from time to time); for the study of transformation parameters, PLATE ISO 294-3 D2 TYPE is prevalently used. It is provided with cavity transducer, which allows important studies about effective pressure load.
Using different size and thicknesses test specimens, the obtained results underline similar trends; however these trends can have sensitively different values.

[A] Used terms and definitions

Data	Definition	Calculus	Practical meaning
Ln	Part nominal length parallel to the injection flow		
Tn	Part nominal length orthogonal to the injection flow		
Lm	Real part measure parallel to the injection flow		
Tm	Real part measure orthogonal to the injection flow		
RL	Molding shrinkage parallel to the injection flow	((Ln-Lm)/Ln)*100 **[%]**	It defines in percentage shrinkage entity parallel to the injection flow: **RLmin; RLmed; RLmax**
RT	Molding shrinkage orthogonal to the injection flow	((Tn-Tm)/Tn)*100 **[%]**	It defines in percentage the shrinkage entity orthogonal to the injection flow: **RTmin; RTmed; RTmax**
RM	Medium molding shrinkage	(RL+ RT)/2 **[%]**	It defines in percentage the medium shrinkage entity: **RMmin; RMmed; RMmax**
RD	Differential shrinkage	RT-RL **[%]**	It defines the difference between RT and RL; the obtained value is inversely proportional to the part planarity: **RDmin; RDmed; RDmax**
WL	Side warpage parallel to the injection flow	((Ln-Lm min)/Tn)*10 **[10^{-2} mm/cm]**	It defines the side warpage entity parallel to the flow, which is how many hundredths of millimeters of bending are obtained for each centimeter of plate length. The obtained value is inversely proportional to the part planarity
WT	Side warpage orthogonal to the injection flow	((Tn-Tm min)/Ln)*10 **[10^{-2} mm/cm]**	It defines the side warpage entity orthogonal to the flow, which is how many hundredths of millimeters of bending are obtained for each centimeter of plate length. The obtained value is inversely proportional to the part planarity
S	Planarity index	Proportional calculus as function of RD e W (100 for RD and W= 0,0 for RD=1 and W= 4)	It defines a significant value of a part dimensional stability considering RD, WL and WT

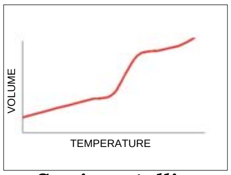
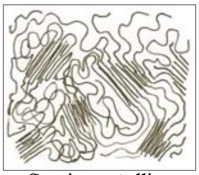
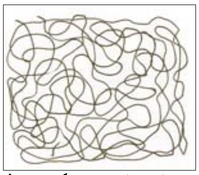
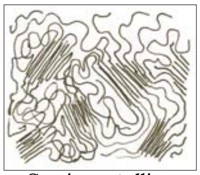
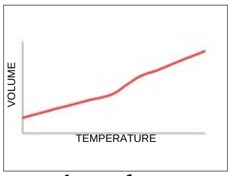
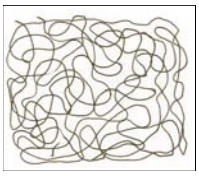
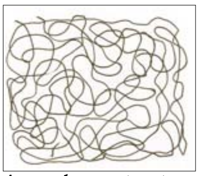
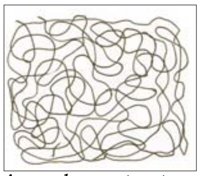
[B] Practical meaning of differential shrinkage and Side warpage

DATA	VALUE	PLANARITY	WARPAGE	DIMENSIONAL STABILITY
RD, differential shrinkage	-0.20÷0.20	EXCELLENT		
	0.20÷0.40	GOOD		
	0.40÷0.60	MIDDLE		
	0.60÷0.80	SCARCE		
	>1.00	VERY BAD		
WL, WT, side warpage	0÷1		VERY LOW	
	1÷2		LOW	
	2÷3		MIDDLE	
	3÷4		HIGH	
	>4		VERY HIGH	
S, dimensional stability	00÷30			VERY BAD
	30÷50			SCARCE
	50÷70			MIDDLE
	70÷90			GOOD
	90÷100			EXCELLENT

2 - SHRINKAGE PHENOMENON

At room temperature, parts, molded with thermoplastic resins, may have some areas in which macromolecules tend to arrange themselves in parallel one to each other (ordered), alternated in region, in which are arranged disorderly. The first one percentage (crystalline), in comparison with the second one (amorphous) determines the crystalline polymer degree. In practice, there are amorphous resins (up to 0%) and semi-crystalline resins (up to 70%).
This condition is extremely important for the shrinkage phenomenon. In fact, among semi-crystalline resins, over glass-transition temperature, macromolecules, arranged in the ordered

[C] Resume

Polymer Specific weight connected to temperature	***Before Transformation*** (Granulate, in hopper)	***Heating effect*** (Melt mass, in plasticizing barrel)	***Cooling effect*** (In the mold cavity)	***Mold shrinkage*** (Influenced factors)
 ***Semi-crystalline***	 *Semi-crystalline structure*	 *Amorphous structure* Weight increase	 *Semi-crystalline structure*	Volumetric shrinkage due to cooling + Molecular organization ***High shrinkage***
 **Amorphous**	 *Amorphous structure*	 *Amorphous structure* *Weight increase*	 *Amorphous structure*	Volumetric shrinkage only due to cooling ***Low shrinkage***

areas, start untying themselves from their structure, obtaining a higher and higher mobility. As soon as the fusion temperature is reached, macromolecules are completely free and the entire mass acquires a totally amorphous structure.
This phenomenon is associated with an important specific volume increase [C].
This is the typical polymer condition before being injected into the cavity mold. As it cools, macromolecules tend to organize themselves according to their own nature: they recover the primary crystalline percentage. In the new reordered areas, the free space among molecules is lower than the amorphous areas: a concrete specific volume reduction ("shrinkage") is thus obtained.

For this reason, ***the higher is the density and the crystalline areas extension, the higher will be the mold shrinkage.***
In the amorphous resins, on the contrary, the cooling has the only effect to cool the structure, without any molecular reorganization. ***The resulting low shrinkage is*** practically ***caused by the reduction of specific volume,*** due to drop in temperature.
The crystalline degree of the part is also influenced by other contingent factors, related to the filling processes (for example nucleations), to the part geometry (especially thickness), to the transformation conditions (temperatures and pressures).

Summarizing, in relation to technical Thermoplastics, it is necessary to consider these variables:

〉 Derived from material:
- Resin nature;
  - ⇒ Semi-crystalline;
  - ⇒ Amorphous.
- Composition:
  - ⇒ Reinforcements;
  - ⇒ Mineral fillers;
  - ⇒ Filling processes.

〉 Derived from part:
- Mold geometry.

〉 Derived from process:
- Transformation parameters.

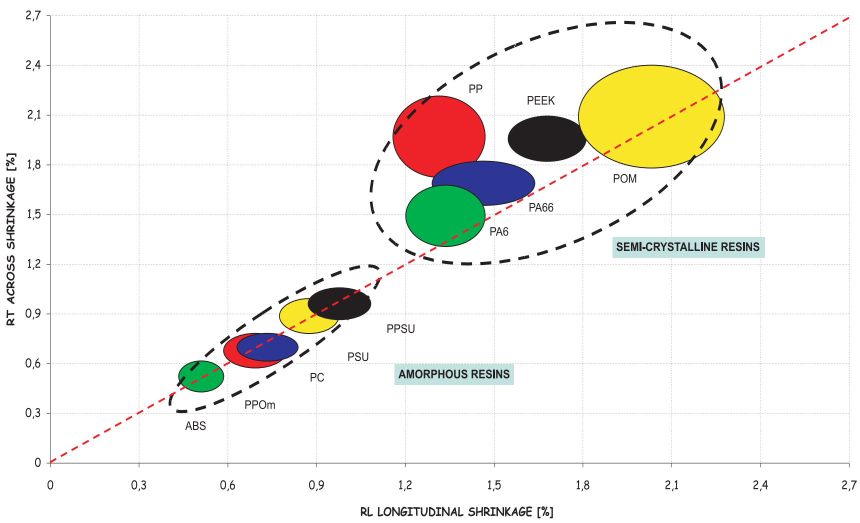
2.1 THE MATERIAL

2.1.1 - RESIN CHEMICAL NATURE

• **Semi-crystalline resins**
Semi-crystalline resins have a high shrinkage tendency during the cooling (1.2÷2.5% on the neat resins); they orientate themselves on the injection flow, allowing the creation of ***differential shrinkage (RD)*** and/or ***warpages (WL-WT)*** easier, above all if they are filled with anisotropic fillers, such as glass and carbon fibers.

• **Amorphous resins**
As amorphous resins have not molecular regularities, which have to be restored during the cooling, they have lower shrinkages (0,4÷1.0%) and they are more dimensionally stable.
In the table D it is reported a resume about molding shrinkage indicative values of the most important neat resins, in their normal transformation conditions.
The diagram 1 represents the ***RL-RT*** correlation and allows to find differences between the two chemical natures. In this diagram it is possible to notice the diagonal broken line, which corresponds to ***RD=0*** (any warpage connected to the differential shrinkage). The positioning along this directrix means planarity and dimensional stability.

[1] RL RT data scattering of the most important neat polymers



[D] - Shrinkage of the most important neat polymers- plate 120 x 80 x 3.5 mm

PRODUCT	RESIN	RL [%]	RT [%]	RD [%]
Semi-crystalline resins				
LATENE	PP	1.50÷2.00	1.80÷2.30	0.20÷0.30
LATAMID 6	PA6	1.25÷1.50	1.35÷1.75	0.10÷0.40
LATAMID 66	PA66	1.35÷1.70	1.65÷2.20	0.10÷0.60
LATER	PBT	2.00÷2.40	2.20÷2.40	0.05÷0.25
LATAN	POM	1.85÷2.35	1.85÷2.50	0.05÷0.25
LARPEEK	PEEK	1.60÷1.85	1.90÷2.15	0.15÷0.40
Amorphous resins				
LASTILAC	ABS	0,45÷0.60	0,45÷0.60	0.00÷0.10
LARIL	PPOm	0,60÷0.80	0,60÷0.80	0.00÷0.10
LATILON	PC	0,65÷0.80	0,65÷0.80	0.00÷0.10
LASULF	PSU	0.80÷1.00	0.80÷1.00	0.00÷0.10
LAPEX R	PPSU	0.90÷1.10	0.90÷1.10	0.00÷0.10

2.1.2 - FILLER PROCESSES, REINFORCEMENTS, FILLERS

• **Filler/reinforcement type**

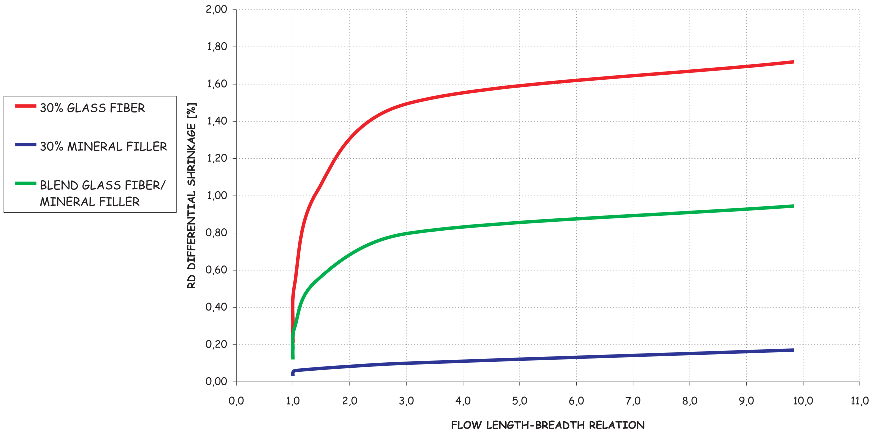
glass fibre, carbon fibre, mica:

these fillers underline remarkably the ***differential shrinkage (RD)*** phenomenon in ***semi-crystalline*** resins. Because of their form (length is much higher than diameter) fibers tend to arrange themselves parallel to the injection flow. This causes an across shrinkage, which is much higher than the along flow. Fiber orientation is also connected to the form factor (***Ln/Tn***) between the two senses. This is demonstrated by the differential shrinkage (***RD***) entity [2], which is an important element for this phenomenon. Thanks to their chemical structure, amorphous resins are affected only in part by shrinkage differences. They keep excellent planarity levels [7].

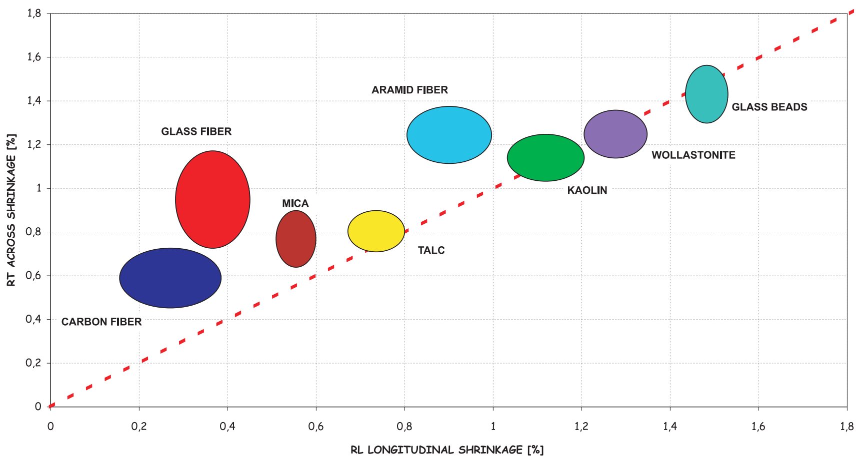
mineral fillers, glass beads:

they are isotropic in shape; they are arranged homogeneous in the melt mass, without following preferential flows. ***They grant low differential shrinkages RD*** [2] and ***low warpages WL-WT***. For this reason, their use is available in those applications, which need good or excellent planarity and dimensional stability (only in semi-crystalline resins).

[2] Differential Shrinkage RD as function of flow length-breadth relation, on rectangular plates



[3] RL RT data scattering of the most important reinforcement types (30%) - PA66; plate120 x 80 x 3.5 mm



[E] - Shrinkage values with different filler reinforcement typologies (30%) - PA66; plate 120 x 80 x 3,5 mm

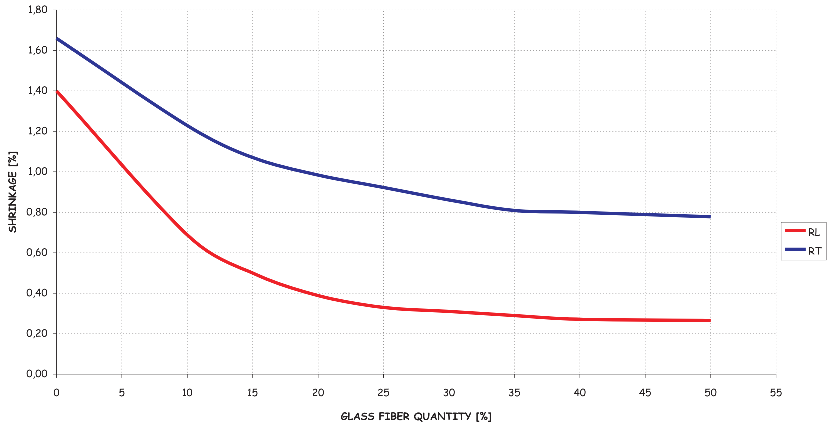
REINFORCEMENT	RL [%]	RT [%]	RM [%]	RD [%]	WL [10^{-2} mm/cm]	WT [10^{-2} mm/cm]
CARBON FIBER	0.15÷0.40	0.65÷0.95	0.40÷0.75	0.50÷0.65	4.90÷5.30	2.10÷2.50
GLASS FIBER	0.30÷0.45	0.70÷1.25	0.70÷0.90	0.65÷1.00	1.20÷1.60	1.45÷2.70
BLEND GLASS FIBER/MINERAL FILLER	0.35÷0.40	0.70÷1.05	0.70÷0.85	0.15÷0.40	1.00÷1.20	1.25÷2.10
TALC	0.65÷0.75	0.80÷0.90	0.70÷0.80	0.00÷0.25	0.55÷0.75	0.70÷0.90
ARAMID FIBER	0.80÷1.00	1.10÷1.40	0.90÷1.20	0.30÷0.50	2.60÷3.10	3.00÷3.50
GLASS BEADS	1.40÷1.55	1.45÷1.75	1.40÷1.60	0.00÷0.30	1.00÷1.20	2.30÷2.50

Blend mineral fillers/glass fibers, milled glass fibers:
have an intermediate behaviour between the two above situations, as a function of percentage relations among different compounds [2].
In the table E it is reported a resume about molding shrinkage indicative values of products filled with the most important type of fillers and reinforcements, used in Thermoplastics. The diagram 3, which represents the ***RL-RT*** correlation, underlines data scattering and allows to individuate differences among different typologies.
In this case too, the diagonal broken line, which corresponds to ***RD=0*** (any warpage connected to the differential shrinkage) is a reference for the excellent planarity situation.

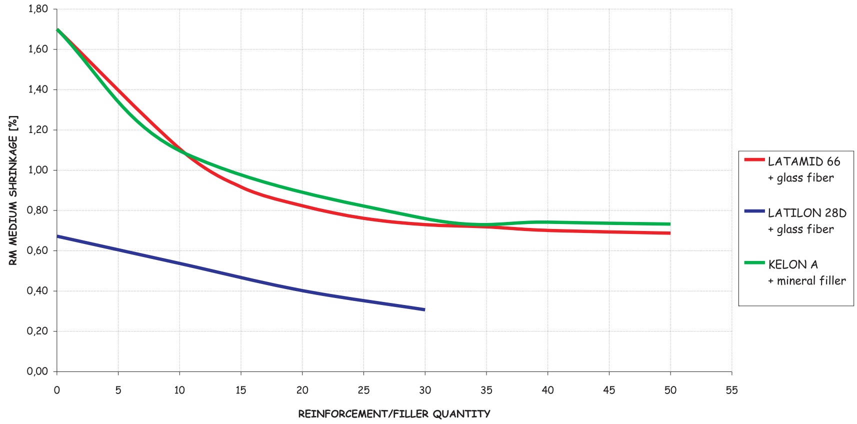
- **Reinforcement/Filler quantity**

Connected to the resin typology the filler percentage influences on the longitudinal ***RL***, across ***RT***, medium ***RM*** and differential ***RD*** shrinkage. In the graph 4 it is reported the value trend of longitudinal ***RL*** and across ***RT*** shrinkage, connected to the glass fiber percentage (PA66). It is possible to notice that over 30% longitudinal variations are rather low.

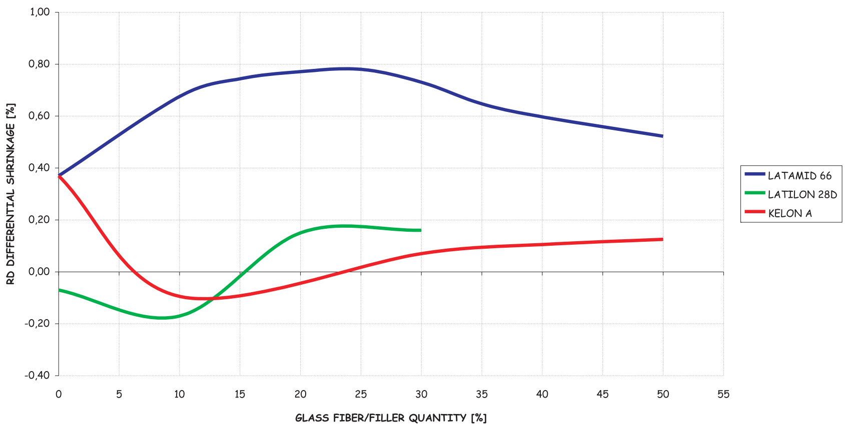
[4] Longitudinal and across shrinkage connected to the fiber percentage PA66; plate 120 x 80 x 3,5 mm



[5] Medium shrinkage RM connected to the filler percentage. PA66 with glass fiber (LATAMID 66), mineral filler (KELON A) and PC (LATILON); plate 120 x 80 x 3,5 mm



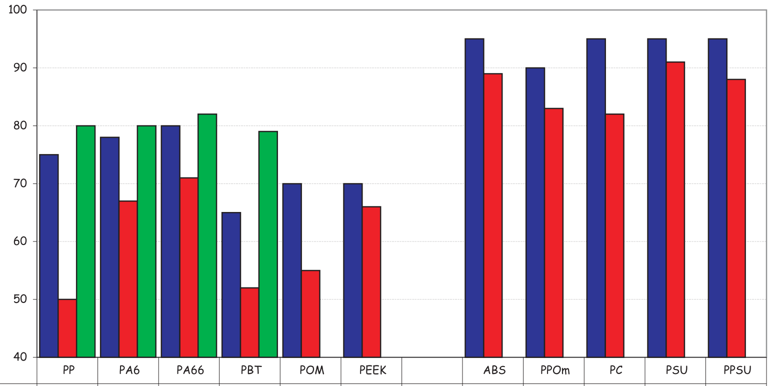
[6] Differential shrinkage RD connected to the filler percentage. PA66 with glass fiber (LATAMID 66), mineral filler (KELON A) and PC (LATILON); plate 120 x 80 x 3,5 mm



The graph 5 describes, connected to the filler percentage, medium shrinkages ***RM*** of a PA66 (with glass fiber and mineral filler) and of a PC (glass fiber). Thanks to the amorphous structure, PC (glass fiber) has low values. On the contrary, in a PA66 the ***volumetric shrinkage is practically constant***, for the same percentage and even changing the filler typology.
But it is associated to a different differential shrinkage ***RD*** [6], maximum in the range of 20÷30%.
In the table F it is reported (see definitions) ***S dimensional stability*** medium values of the most

important neat resins, with 30% glass fiber or mineral filler. In this case too, the material chemical structure plays an important role; amorphous resins, even when they are filled, keep excellent or good dimensional stability values. Semi-crystalline resins can reach the same level only with mineral fillers. This phenomenon is described in the histogram 7.

[7] Dimensional stability (S) of the most important polymers with 30% of glass fiber and 30% of mineral filler. Plate 120 x 80 x 3,5 mm



	PP	PA6	PA66	PBT	POM	PEEK		ABS	PPOm	PC	PSU	PPSU
NEAT RESIN	75	78	80	65	70	70		95	90	95	95	95
30% GLASS FIBER	50	67	71	52	55	66		89	83	82	91	88
30% MINERAL FILLER	80	80	82	79								

[F] - Dimensional stability of the most important polymers with 30% of glass fiber and 30% of mineral filler - plate 120 x 80 x 3,5 mm

PRODUCT	RESIN	NEAT RESIN	30 % GLASS FIBER	30 % MINERAL FILLER
Semi-crystalline resins				
LATENE	PP	60÷75	40÷50	71÷80
LATAMID 6	PA6	68÷78	52÷67	69÷80
LATAMID 66	PA66	72÷80	57÷71	72÷82
LATER	PBT	55÷65	38÷52	68÷79
LATAN	POM	60÷70	45÷55	-
LARPEEK	PEEK	60÷70	51÷66	-
Amorphous resins				
LASTILAC	ABS	85÷95	78÷89	-
LARIL	PPOm	80÷90	75÷83	-
LATILON	PC	85÷95	80÷82	-
LASULF	PSU	85÷95	80÷91	-
LAPEX R	PPSU	85÷95	80÷88	-

- **Additives**

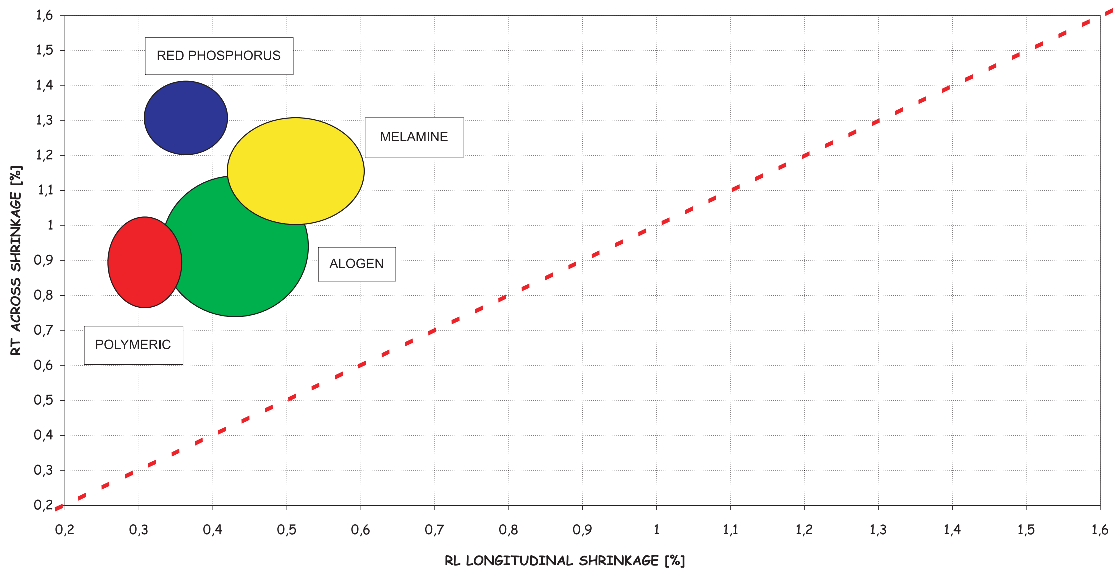
Thermoplastic materials contain specific additives to ensure or improve important features such as self-extinguish, lubrication, stabilization and pigmentation. Their presence has an effect on the shrinkage behaviour. In the table G it is reported a resume of shrinkage values, obtained with the most important types of self-extinguish compounds.

The diagram 8 describes the ***RL-RT*** correlation, underlines data scattering and allows to individuate differences between various typologies.
In this case too, it is possible to compare values with the broken line (***RD=0***), as in the

[G] - Type of self-extinguishing influence- PA66 25% glass fiber; plate 120 x 80 x 3,5 mm

ADDITIVE	**RL [%]**	**RT [%]**	**RM [%]**	**RD [%]**	**WL** [10^{-2} mm/cm]	**WT** [10^{-2} mm/cm]
Polymeric self-extinguishing agent	0.25÷0.40	0.75÷1.00	0.50÷0.70	0.40÷0.65	0.60÷1.50	1.30÷2.50
Alogen self-extinguishing agent	0.35÷0.55	0.75÷1.15	0.55÷0.85	0.20÷0.70	1.80÷2.50	3.00÷4.00
Self-extinguishing agent with Melamine salt	0.45÷0.65	1.00÷1.30	0.70÷0.95	0.40÷0.90	2.30÷3.00	1.50÷2.50
Self-extinguishing agent with red phosphorus	0.35÷0.45	1.20÷1.40	0.80÷1.00	0.70÷1.00	0.80÷2.00	1.25÷2.50

[8] RL RT data scattering of the most important self-extinguishing agents. PA66 25% glass fiber; plate 120 x 80 x 3,5 mm

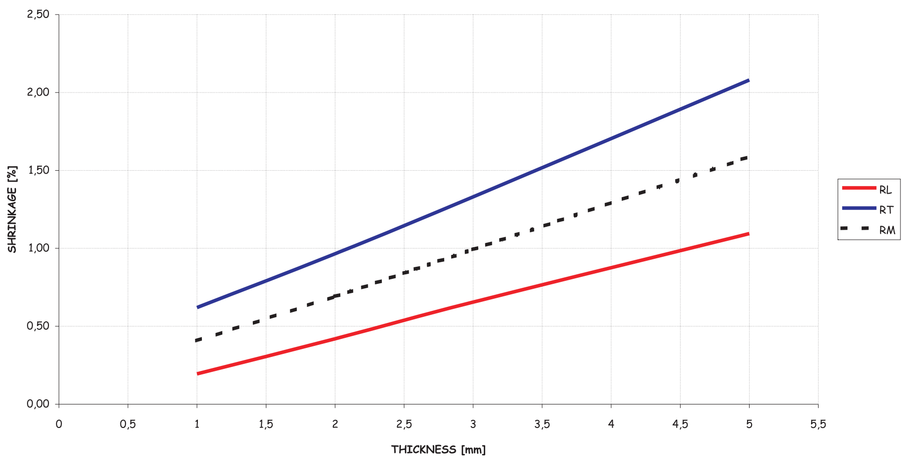


previous cases.

2.2 THE PART GEOMETRY

Injection-molded parts represent a mix view of situations, comparable to a whole of geometric elements, variable in form, complexity, size and surface. Thickness and flow length, runner size and gate geometry play an important role: they influence directly the pressure entity, which is produced during the filling phase. ***The obtained shrinkage is the consequence of a more or less load loss***, verified

[9] Longitudinal, across and medium shrinkage connected to the part thickness - PA66 30% glass fiber; plate ISO 294-3 60 x 60; pressure in cavity at 400 bar

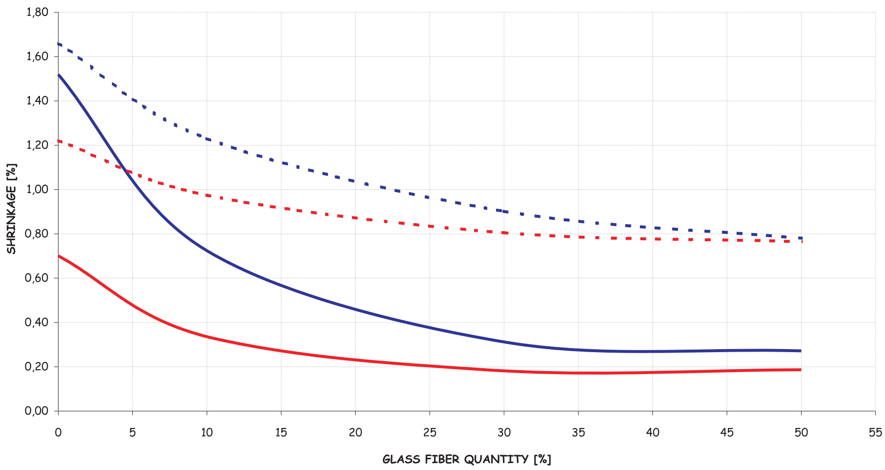


during the process.

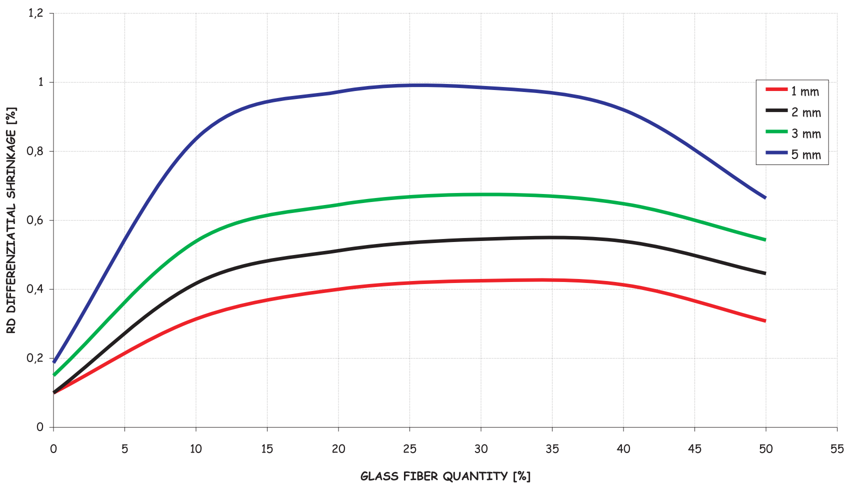
2.2.1 - THICKNESSES

The results in the graph 9 describe the strictly connection between molding shrinkage (at the same circumstances) and part thickness. Molding shrinkage is directly proportional to thickness (it doubles with thickness doubling).
The phenomenon reduces itself lenghting the flow path or elevating the filler level.
In the example [10] it is possible to notice that, increasing the fiber percentage, the variation between the shrinkage measured on the major and minor thickness tends to 0 (in the case of across sense [***RT***]).

[10] Longitudinal, across shrinkage connected to the part thickness and glass fiber percentage; PA66; plate 120 X 80 x 3,5 mm

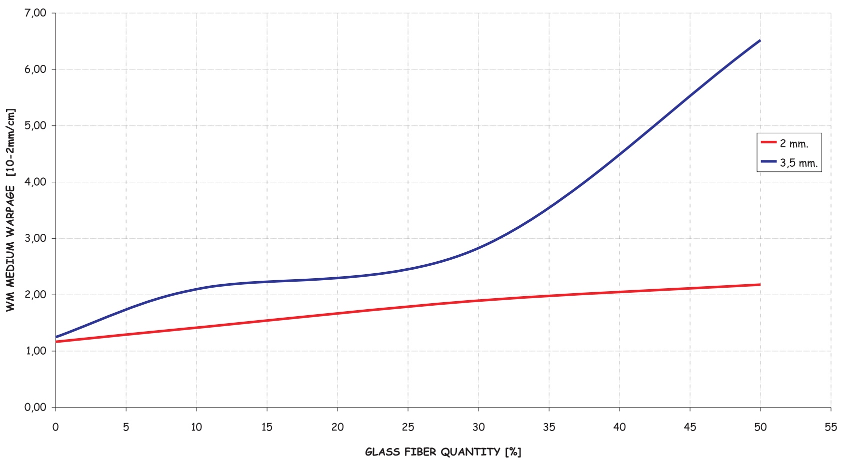


[11] Differential shrinkage connected to the part thickness and glass fiber percentage - PA 66; plate ISO 294-3 60 x 60; cavity pressure 600 bar



Differential shrinkage ***RD*** [11] describes a trend, which is proportional to the thickness and reaches maximum values around 20÷30% (see graph 6).

[12] Warpage connected to the part thickness and glass fiber percentage - PA66; plate 120 x 80 x 3.5 mm

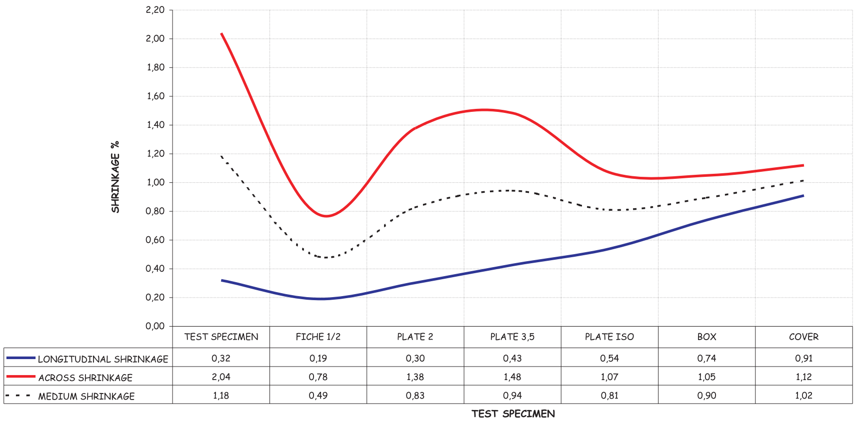


According to the side Warpage trend ***WM*** [12] it is obtained higher and higher values for the major thickness because of a little increase for the lowest thickness.

2.2.2 - FLOW LENGHT, PART GEOMETRY, INJECTION SECTION

The analysis has been carried out on 7 different types of moulded parts, with different thicknesses, flows and injection sections. As it is possible to notice [H, 13], there is a wide range of data, in the longitudinal sense ***RL*** (0,19÷0,91%) and in the across ***RT*** sense (0,78÷1,48%). The high result scattering (it has not been possible to individuate any practical correlation between the independent variables and the obtained results) brings to the conclusion that ***every object***, with its own geometries, ***has particular behaviours of molding shrinkage.*** These are difficult to reproduce on test specimens with different shapes, excepting through precise flow simulation analyses.

[13] Longitudinal, across and medium shrinkage calculated on different types of test specimens-PA 66 30% glass fiber



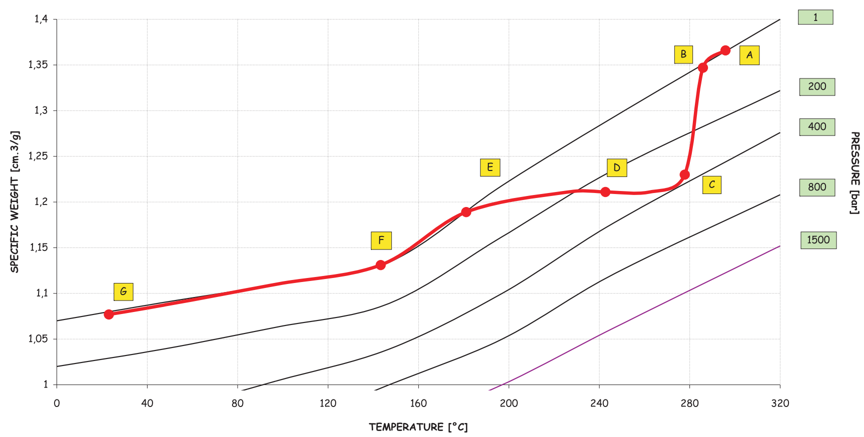
[H] - Test specimens used for the measurement and obtained results; PA66 30% glass fiber

TEST SPECIMEN	SHAPE	SIZE			INJECTION [mm]	VOLUME [cc]	GATE AREA [cm²]	RL [%]	RT [%]	RM [%]	RD [%]
Test specimen	Rectangular	125	12.7	3.2	Side 3.0 x 10	5.1	0.30	0.32	2.04	1.18	1,72
Plate	Rectangular	120	80	3.5	Laminar 1 x 80	33.6	0.8	0.43	1.48	0.94	1,05
Plate	Rectangular	120	80	2.0	Laminar 1 x 80	19.2	0.8	0.30	1.38	0.83	1,08
Plate	Rectangular	110	55	1÷2	Side 2 x 12	9.1	0.24	0.19	0.78	0.49	0,59
Plate ISO 294 type D2	Rectangular	60	60	2.0	Laminar 0,75 x 60	7.2	0.45	0.54	1.07	0.81	0,53
Box	Base	80	80	0.5÷6	Capillar	24.4	0.03	0.74	1.05	0.90	0,31
Box	Cover	80	80	2.5÷	Capillar	30.6	0.03	0.91	1.12	1.02	0,21

2.3 TRANSFORMATION PARAMETERS

The material shrinkage begins during the holding pressure application and continues through the cooling phase, until the complete part solidification at room temperature. These are the basic phases; the pressure on the part reduces the shrinkage of the same, conditioning the entity. The best instrument to analyze this aspect is the ***PVT diagram*** [I, L]: it studies the correlation

[I] Diagram PVT in the molding injection cycle of a PA66



[L] - Diagram phases in the injection molding

STEP	MOLDING CYCLE PHASE	TEMPERATURE	PRESSURE	VOLUME
A	Filling start	Molding melt temperature	Atmospheric pressure	Volume corresponds to the highest expansion
B	Filling end- holding start	Constant (little decrease)	Constant or little increase, till complete filling	Little decrease
C	Highest pressure reached-part solidification start	Constant (little decrease)	It increases quickly	It decreases quickly
D	Holding end- cooling pause start	Decreases	It decreases quickly	Little decrease
E	Cooling pause- atmospheric pressure reaching	Decreases	Atmospheric pressure is reached	Decreases
F	Ejection	Decreases	Atmospheric pressure	Decreases
G	Final state	Room temperature	Atmospheric pressure	Final volume

among temperature, specific volume and pressure; it gives also important information about the material behavior, when it is heated/cooled under the pressure load effect.
The volume difference, surveyed between A and G points, corresponds to the real value of molding shrinkage.
Some of the singular phases are going to be analyzed deeply.

2.3.1 INJECTION AND HOLDING PHASE

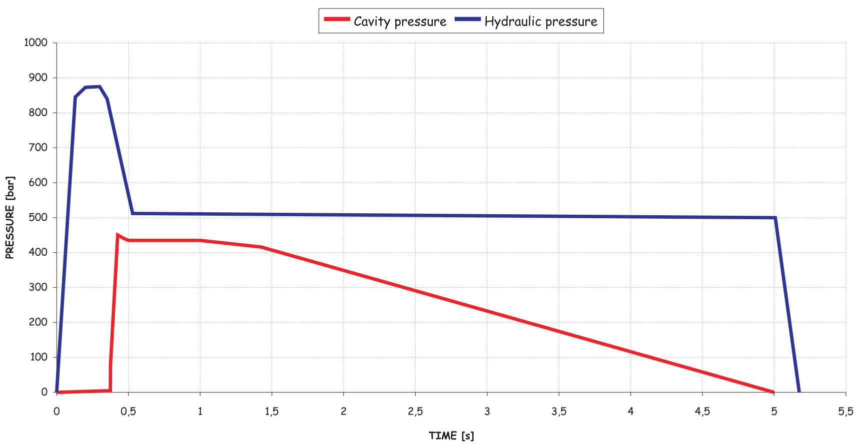
- **injection**

In this phase the material is transferred, through the nozzle, from the barrel to the mould. The screw works as piston and exerts a pressure on the polymer, which increases with slopes proportional to the material viscosity and nozzle speed, until the switching point [14]. The holding phase starts. Any incorrect formulation of ***this parameter*** (advanced-delayed in comparison with the effective mold filling), besides creating different problems, influences on the pressure load in cavity and consequently on the shrinkage entity.

- **holding**

During the holding phase, it is verified a difference between the pressure, applied by the screw (constant) and the real pressure in the cavity [14], which decreases with the holding pressure application. This is caused by the progressive gate and part solidification. Because of the higher and higher part viscosity, there is a lower transmission of hydraulic pressure, applied by the screw (load loss).
As soon as the gate solidification is reached (time is variable in function of its section), cavity pressure is null and any further holding pressure

[14] Hydraulic and cavity pressure during injection and holding phase; plate ISO 294-3 60 x 60 x 2.0 mm



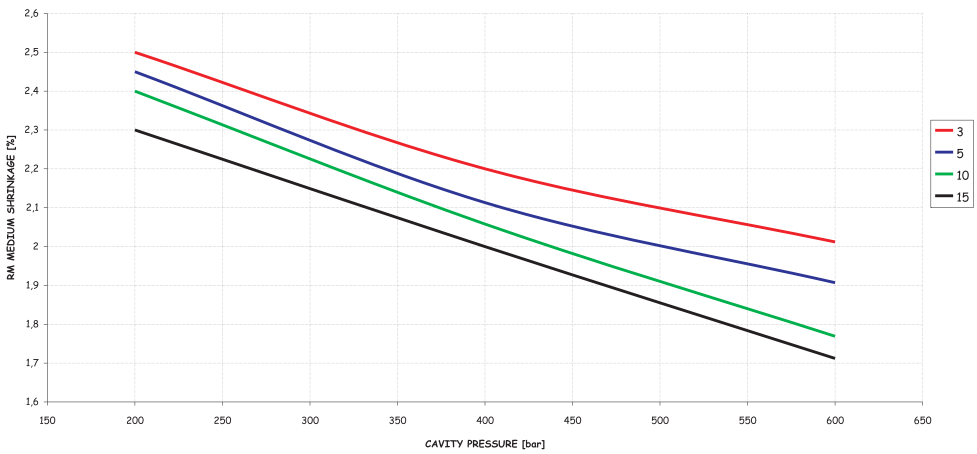
application is irrelevant.
This is an important phenomenon because the derived molding shrinkage is directly connected to the effective pressure in cavity.
Moreover, some material features (fluidity) and some transformation parameters (melt temperature and/or mould temperature) allow more or less

load loss for the same applied pressure.
In the graph 15 and 16 it is reported the medium shrinkage trend of a PA66, in function of the cavity pressure (in different times) and holding time.
It is possible to notice that shrinkage decreases with the pressure increase and describes a temporal curve: beyond a certain point no real effect exists any more.
This time corresponds to the complete solidification of the injection section; screw pressure has any more practical effect on the real pressure in the mould.
WM side warpage presents, on the contrary, a trend that is inversely proportional to the applied pressure [17], but it is directly proportional to its duration [18].

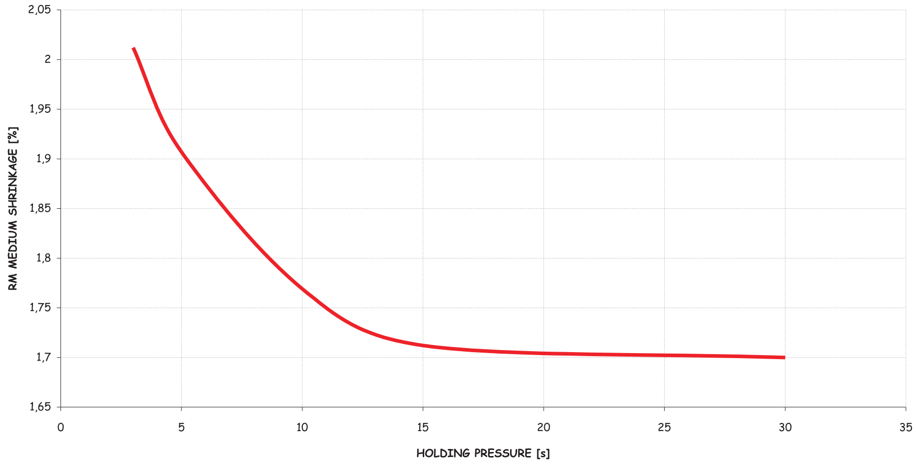
2.3.2 - COOLING

In semi-crystalline resins, if mould temperature and holding pressure time are correct, the part will reach the highest crystalline level and the cooling pause will ensure the complete solidification of it.
In this case, molding shrinkage will be inversely

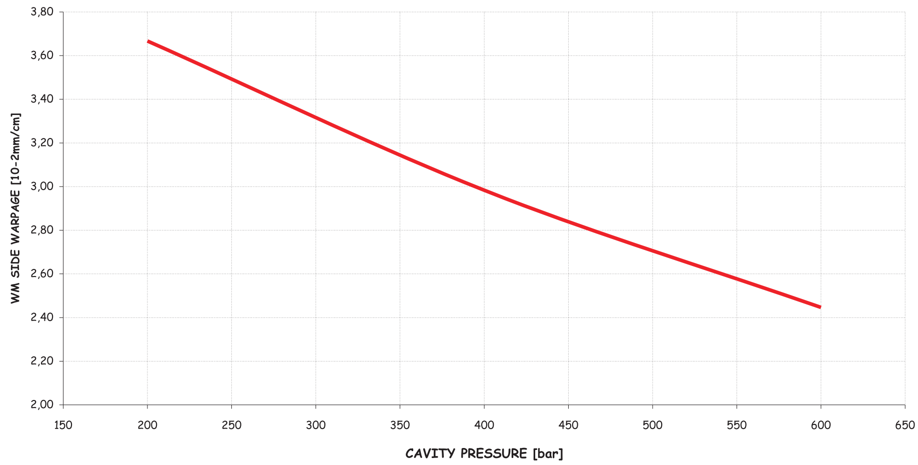
[15] Medium shrinkage connected to the cavity pressure with different type of holding - Neat PA66; plate ISO 294-3 60 x 60 2,0 mm



[16] Medium shrinkage connected to the holding time - Neat PA66; plate ISO 294-3 60 x 60 x 2.0mm; cavity pressure 600 bar



[17] Side warpage connected to cavity pressure- Neat PA66; plate ISO 294-3 60 x 60 x 2.0 mm



proportional both to the cooling time and to the applied pressure [19].

2.3.2 TEMPERATURES

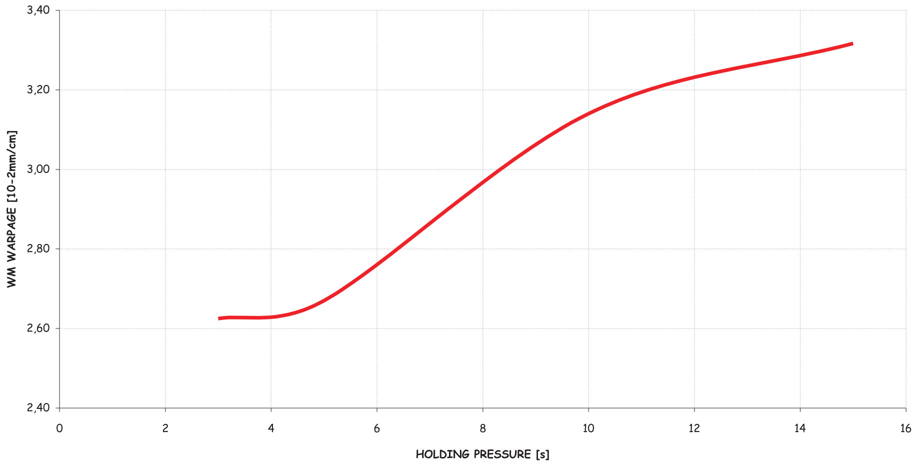
- **Melt**

Melt temperature has a direct effect on the pressure transmission from the screw to the cavity (the higher is the temperature, the higher is the material fluidity; consequently the higher is the transmitted pressure). If any adjustment on the holding value is made to keep constant cavity pressure, there will be an inversely relation between temperature and shrinkage.

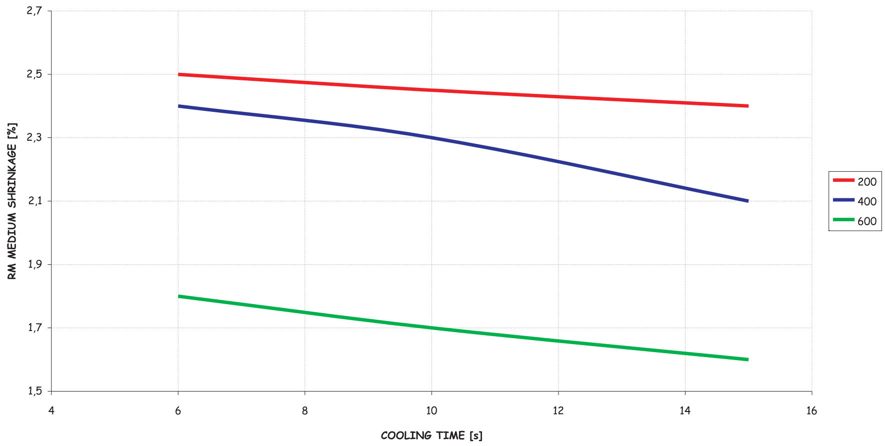
In the example [20] it is reported (for a PA6/66 self-extinguish Halogen free) the medium shrinkage **RM** trend connected to the Melt temperature, without and after compensation, at 600 bar in cavity.

In the second case, there is not any important variation; for this reason **Melt temperature is not directly connected to the shrinkage, but it has an effect on the**

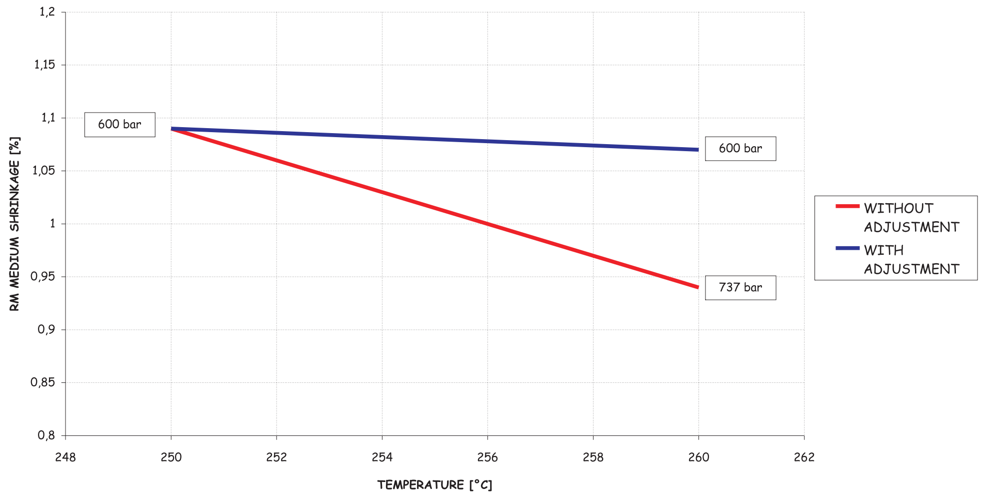
[18] Side warpage connected to the holding time - Neat PA 66; plate ISO 294-3 60 x 60 x 2.0 mm; cavity pressure 600 bar



[19] Medium shrinkage connected to the cooling time with different cavity pressure values - Neat PA 66; plate ISO 294-3 60x60x2.0 mm



[20] Medium shrinkage connected to melt temperature - PA 6/66 self-extinguishing halogen free; plate ISO 294-3 60 x 60x 2.0 mm; with or without adjustment of cavity pressure at 600 bar

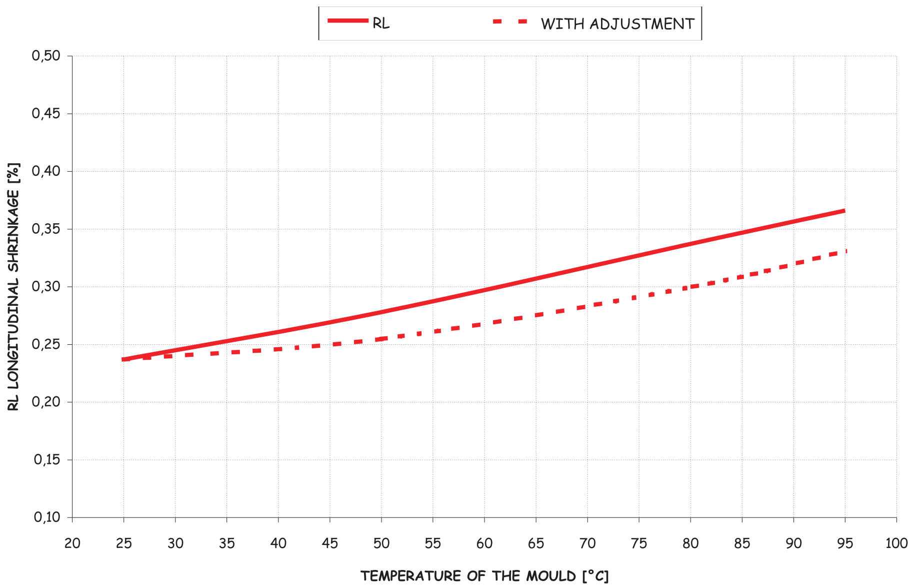


shrinkage because it causes the cavity pressure increase.

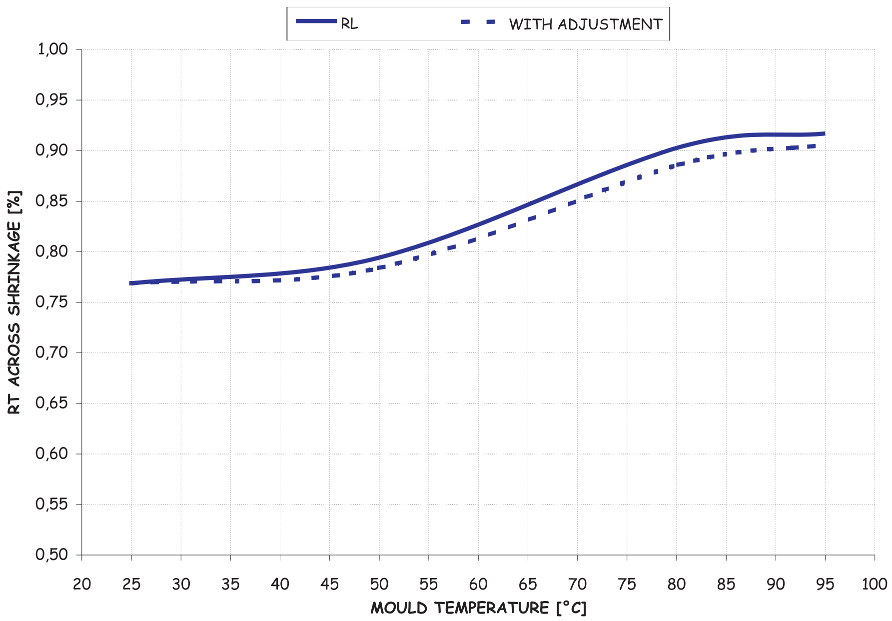
- **Mould**

The material structure is very important: semi-crystalline resins need a temperature higher than their glass transition. Under this temperature level material could freeze in an improper amorphous structure. The result is a low molding shrinkage [21, 22] but by the time the part will recover its original crystalline structure, creating warpage problems (**post shrinkage**). This phenomenon will be relevant when the part working temperature is higher than mold temperature during the transformation. In amorphous resins, on the contrary, mould heating is made to improve the melt mass flow in the cavity, without having real effects on shrinkage properties. Mould temperature, moreover, has only a little influence on the pressure load in cavity. This can be verified in the graph 21-22, in which there is a little difference among the obtained curves, with or without adjustment at 400 bar.

[21] Medium Longitudinal shrinkage connected to molding temperature. PA 66 30% glass fiber; plate ISO 294-3 60 x 60 x 2.0 mm; with or without adjustment of cavity pressure at 400 bar



[22] Medium Across shrinkage connected to mould temperature- PA 66 30% glass fiber; plate ISO 294-3 60 X60 2.0 mm; with or without adjustment of cavity pressure at 400 bar



3 - SUMMARY

	Shrinkage	Warpage	References (Graph number)
Resin features			
Semi-crystalline resin	↑	↑	1,7
Amorphous resin	↓	↓	1,7
Glass fibre reinforcement	↓	↗↘	3,4,6,7,10,11,12
Mineral filler	↓	→	3,5,6
Self extinguishing agent	↓	↓	8
Mould geometry			
Thickness	↑	↑	9,10,11,12
Flow length	↑	↑→	2
Transformation parameters			
Cavity pressure	↓	↓	15,17,19,20,21,22
Holding pressure time	↓→	↑	15,16,18
Cooling time	↓	↓	19
Melt temperature	↑	→	20
Mould temperature	↑	↑	21,22

Key

↑ = directly proportional

↑→ = directly proportional, then stable

↗↘ = directly proportional, then inversely proportional

⇒ = stable

↓ = inversely proportional

↓→ = inversely proportional, then stable

4 – REFERENCES AND BIBLIOGRAPHICAL SOURCES

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