Simulation study of the effect of coolant temperature on injection molding quality

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Abstract: *As plastic products shrink during cooling, so knowledge of shrinkage factor for different materials is required. The main objective of the study is to examine the influence of mold cooling process on subsequent deformation of finished part. To achieve the goal, simulations were carried out at different temperatures of the cooling agent. Statistical processing was performed and a regression model was derived describing the relationship between temperature, time and deformation during cooling.*

Keywords*: 3D MODEL, CAE, SIMILATION, INJECTION MOLDING, REGRESSION MODEL, OPTIMIZATION*

1. Introduction

Over the last decade, use of plastic products has increased at an extremely rapid pace, with continuous market pressure for higher quality products at lower prices. All this predetermines wider application of methods and means for optimizing the technological parameters of the process.

. As a result, adequate design of plastic parts is a current problem, especially in light of increasingly active use of computer technology, as a powerful source to accelerate development process. Through methods of virtual prototyping, possibilities of improving quality and reducing costs are higher [1-5].

2. Materials and methods

Since cooling time of the product accounts 80% of the entire molding cycle, in order to improve the molding efficiency and shorten the molding cycle, an effective cooling system should be selected. The cooling system also has a great influence on the deformation of the parts. Uniform cooling can greatly reduce deformation and improve product quality [6-10]

The purpose of the experiment is to simulate and optimize the cooling system of the injection molding and to achieve the required quality of a part.

The object of the research is an aunt for a tee. The 3D model of the experimental specimen is shown in (Fig.1). It has overall dimensions of 104 x 63.5 mm and the material used for its production is HIPS.

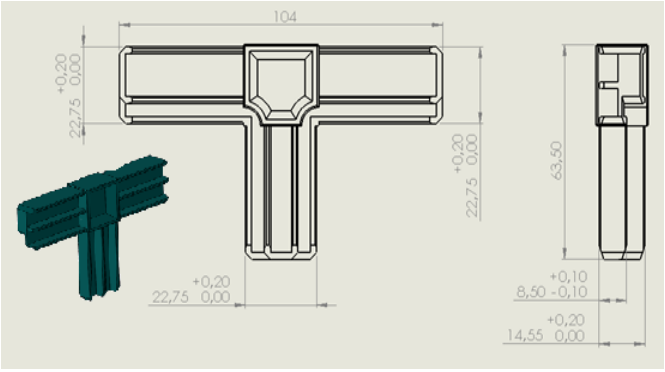

Fig. 1. *3D model "Tee"*

Simulation studies were performed at 5 different temperatures as follows - 5°C, 10°C, 20°C, 30°C and 40°C.

A simulation of the cooling process was carried out in Moldex 3D. The effect of water temperature on the part and the results of deformation during shrinkage are presented as follows:

- Water temperature 5°C

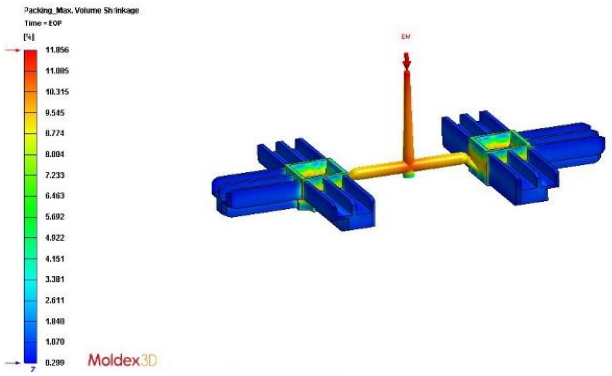

Fig. 2. *Shrinkage, temperature of water - 5°C*

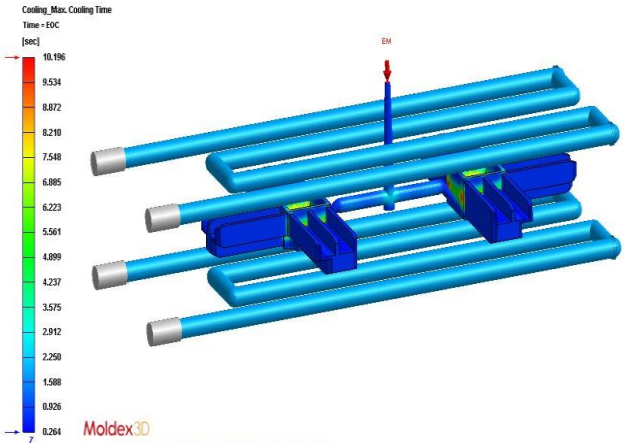

Fig. 3. *Cooling time, temperature of water - 5°C*

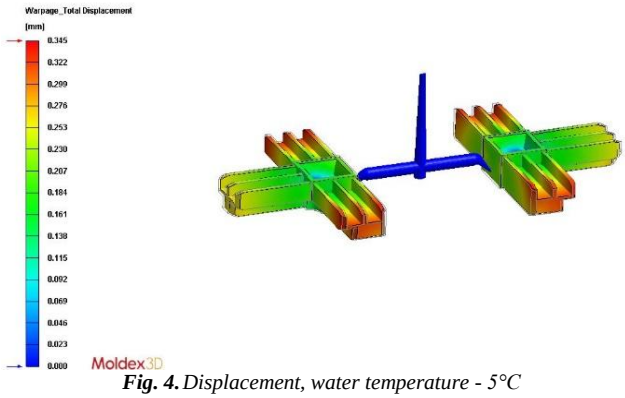

Fig. 4. *Displacement, water temperature - 5°C*

- Water temperature 10°C

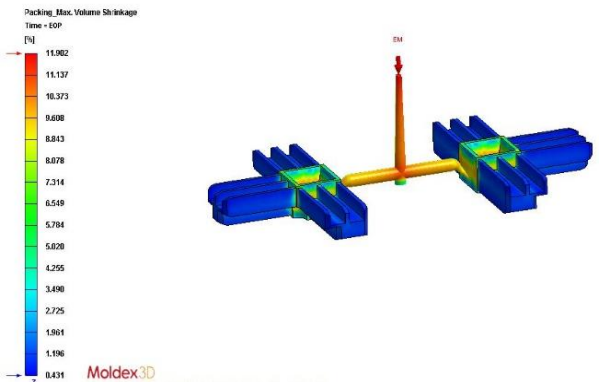

Fig. 5. *Shrinkage, water temperature - 10°C*

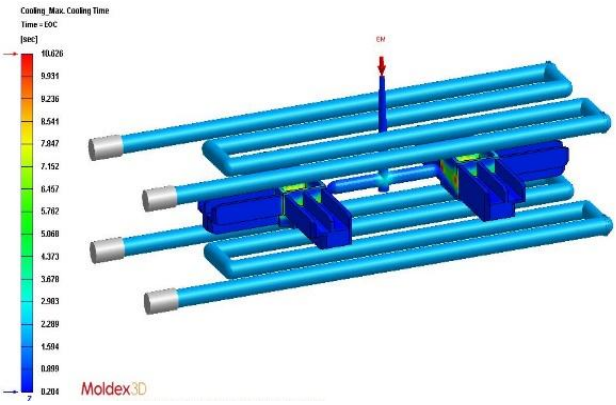

Fig. 6. *Cooling time, water temperature* - 10°C

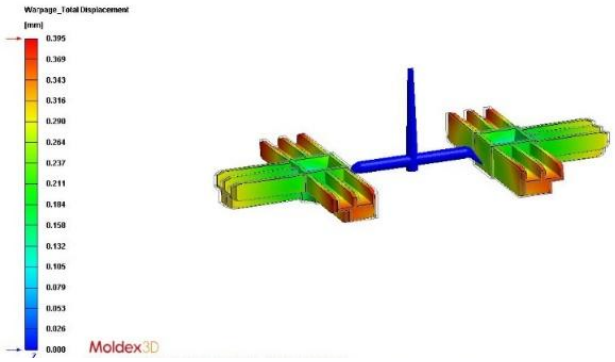

Fig. 7. *Displacement, water temperature* - 10°C

❖ Water temperature 20°C

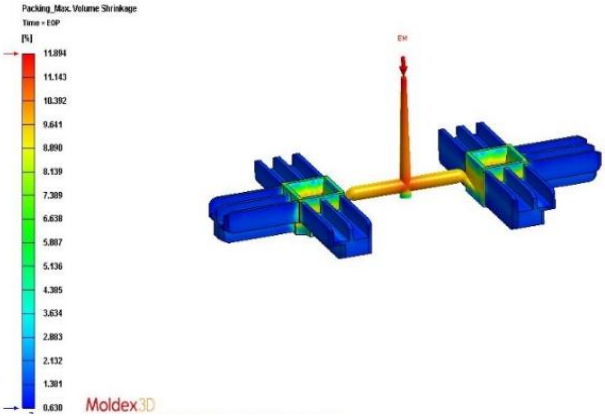

Fig. 8. *Shrinkage water temperature - 20°C*

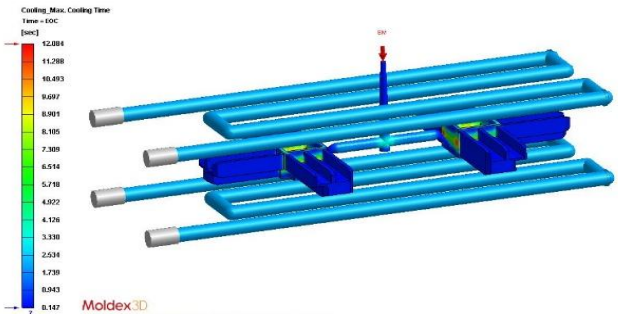

Fig. 9. *Cooling time, water temperature* - 20°C

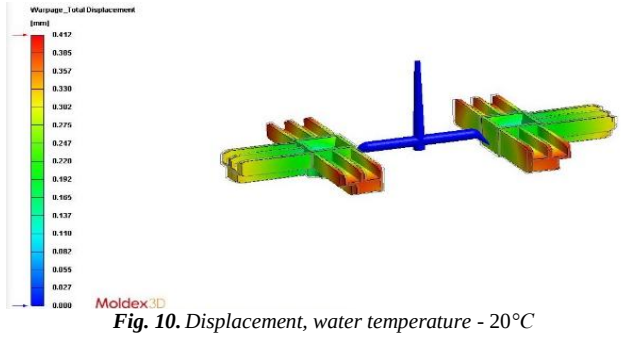

Fig. 10. *Displacement, water temperature* - 20°C

❖ Water temperature-*30°C*

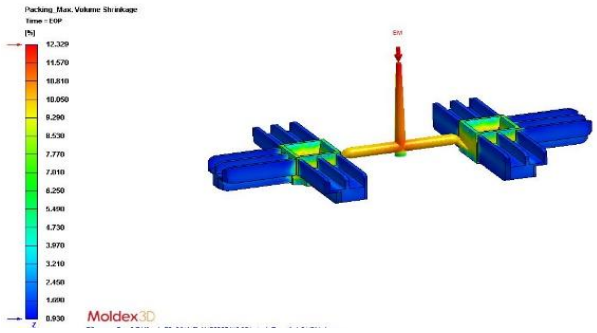

Fig. 11. *Shrinkage ,water temperature* - 30°C

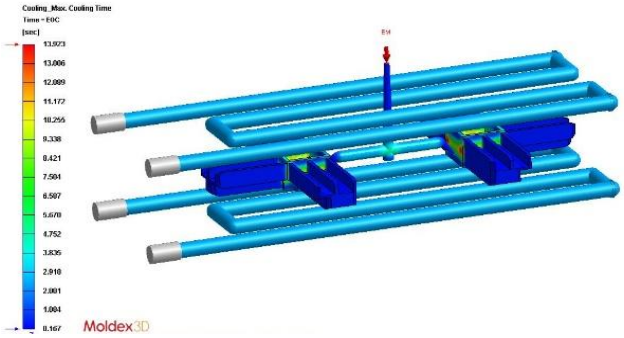

Fig. 12. *Shrinkage, water temperature* - 30°C

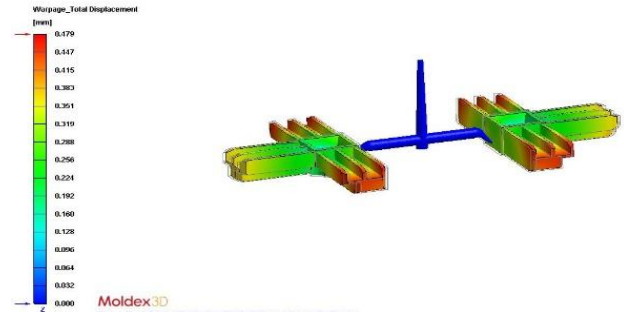

Fig. 13. *Displacement, water temperature* - 30°C

- Temperature of water - 40°C

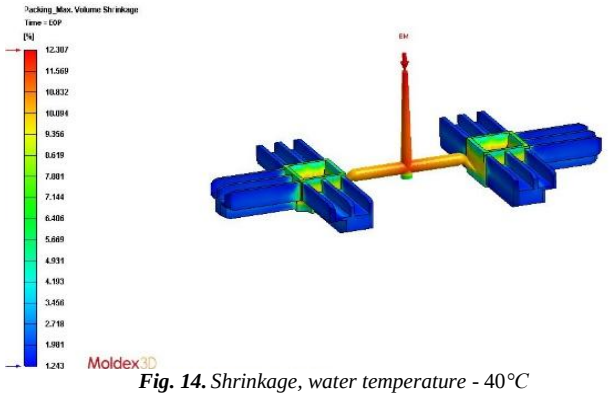

Fig. 14. *Shrinkage, water temperature* - 40°C

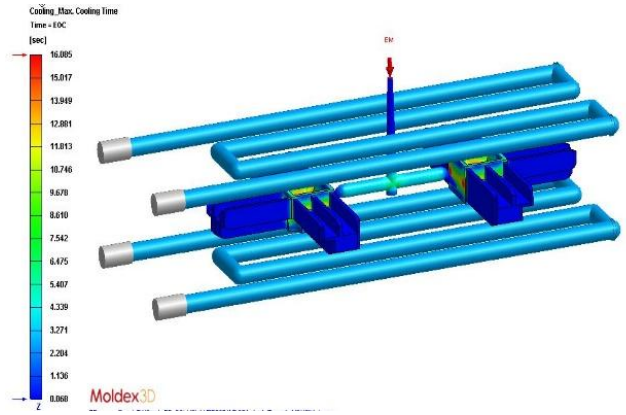

Fig. 15. *Cooling time, water temperature* - 40°C

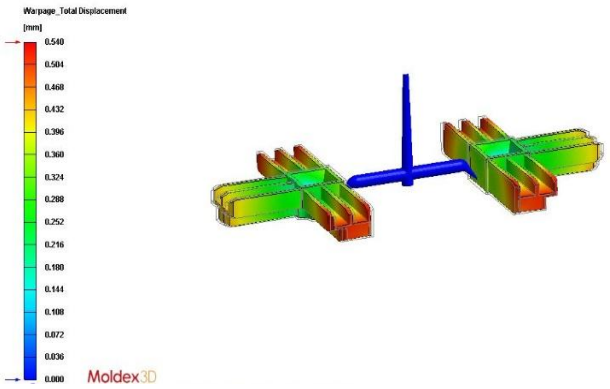

Fig. 16. *Displacement, water temperature* - 40°C

3. Statistical processing of the obtained results

Results are presented in tubular form, tables-1.

Table 1: *Results*

Tw °C	Ts	D [mm]	S [%]
5	10,196	0,345	11,856
10	10,626	0,412	11,894
20	12,084	0,395	11,902
30	13,923	0,479	12,329
40	16,085	0,54	12,307

Where:

- Tw-water temperature;
- Ts-cooling time;
- D-displacement [mm];
- S-shrinkage [%]

Mathematical and statistical processing was performed with the software product MINITAB for mathematical description of the objective function D (displacement), table 2-4.

The data in the table. 1 are processed and the following regression model is obtained:

D =5,6712 + 0,042998 Tw + 0,004512 Tw*Tw - 0,05438 Ts*Ts, (1)

Table 2: *Model summary*

S	R-sq	R-sq(adj)	Press	R-sq(pred)	AICc	BIC
0,0008511	100,00%	99,99%	0,0000291	99,87%	*	-56,50

Table 3. *Coefficients*

Term	Coef	SE Coef	95%Cl	T-Value	P-Value	VIF
Constant	5,6712	0,0996	(4,4056; 6,9368)	56,94	0,011	
Tw	0,042998	0,000782	(0,033058; 0,052937)	54,97	0,012	692,68
Tw*Tw	0,004512	0,000083	(0,003455; 0,005570)	54,21	0,012	16355,18
Ts*Ts	-0,05438	0,00102	(-0,06732; -0,04145)	-53,41	0,012	23472,10

Table 4 *Analysis of variance*

Source	DF	Seq SS	Contribution	Adj SS	Seq MS	F-Value	P-Value
Regression	3	0,023186	100,00%	0,023186	0,007729	10668,83	0,007
Tw	1	0,020741	89,45%	0,002189	0,020741	28630,85	0,004
Tw*Tw	1	0,000379	1,63%	0,002129	0,000379	523,28	0,028
Ts*Ts	1	0,002066	8,91%	0,002066	0,002066	2852,36	0,012
Error	1	0,000001	0,00%	0,000001	0,000001		
Total	4	0,023187	100,00%				

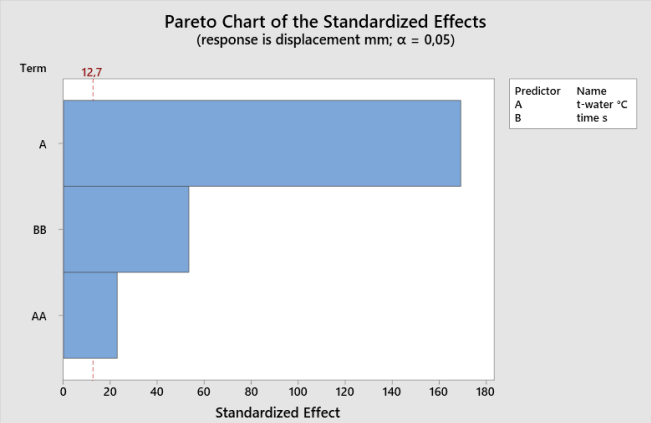

Fig. 17. *Standardized residuals*

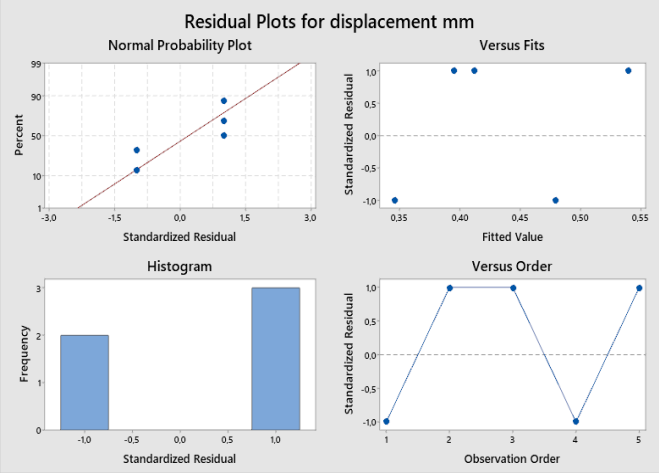

Fig. 18. *Standardized residuals*

The analysis of the standardized residuals was done. (Fig. 18).

The analysis of the residuals does not indicate a deviation of the assumptions of regression analysis. Fig.18 shows that all residuals are in the range (-2; 2). Therefore, it can be concluded that there are not significant errors.

4. Optimization

One-parameter shrinkage optimization D[mm] was made. The optimal value sought is 0, i.e. minimal displacement of the part. The optimization data is presented in tables 5-7.

Table 5: *Parameters*

Response	Goal	Lower	Target	Upper	Weight	Importance
D [mm]	Target	-0.2	0	0.54	1	1

Table 6: *Decision*

Solution	Tw	Ts	Fit	Desirability
1	10,1385	10,9920	-0,0000000	1

Table 7: *Optimum predicted shrinkage value*

Tw	10,1385			
Ts	10,992			
Response	Fit	SE Fit	95% CI	95% PI
D [mm]	-0,00000	0,00710	(-0,09024; 0,09024)	(-0,09089; 0,09089)

Graphical optimization of displacement is shown in Fig. 19.

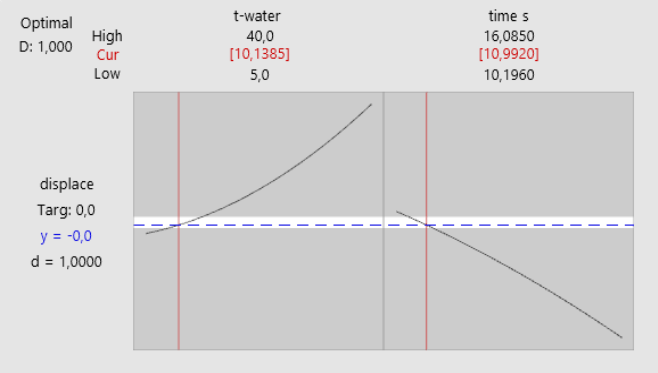

Fig. 19. *Optimization diagram*

The following results are obtained from the optimization made using the MINITAB software:

- Tw = 10,1385 ° C
- Ts = 10,9920 s

A diagram of the effect of each factor on the objective function (shrinkage D [mm]) is shown, Fig. 20.

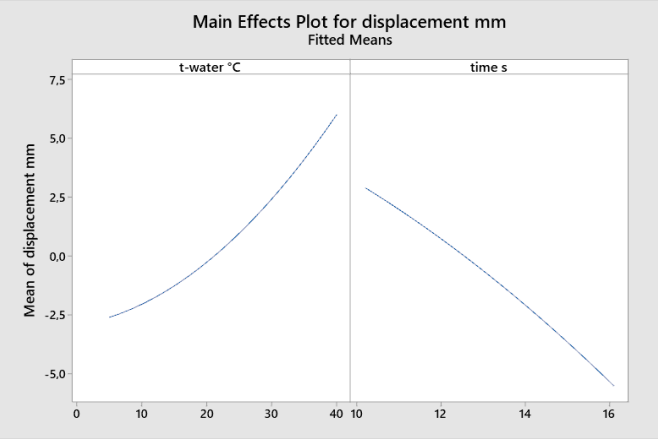

Fig. 20. *Influence of the factors*

Contour diagram of D is shown fig.21.

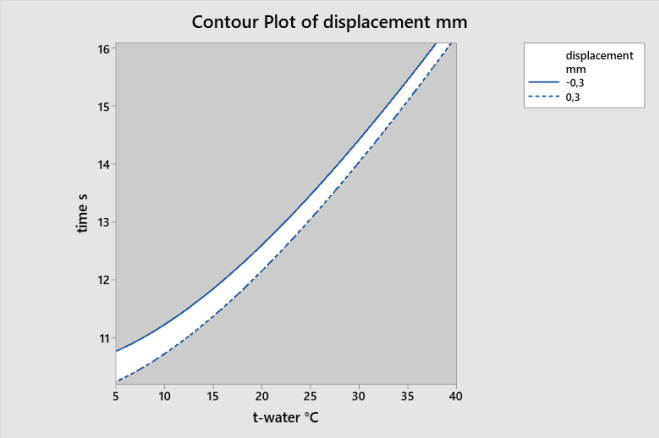

Fig. 21. *Contour diagram*

5. Conclusion

A manufacturer of plastic products was assigned for making a tee, fig.1. The focus of the project was to optimize cooling and to ensure quality. A simulation of the cooling system was carried out in the range of 5°C to 40°C. Resources were saved using a simulation.

At the conclusion of the experiment, obtaining a regression model and the subsequent optimization, the following conclusions are drawn:

- The optimal cooling parameters are: cooling fluid temperature 10.2°C and cooling time 11s.
- The largest influence on the displacement, as assumed, is the temperature of the fluid around 90%.

6. References

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