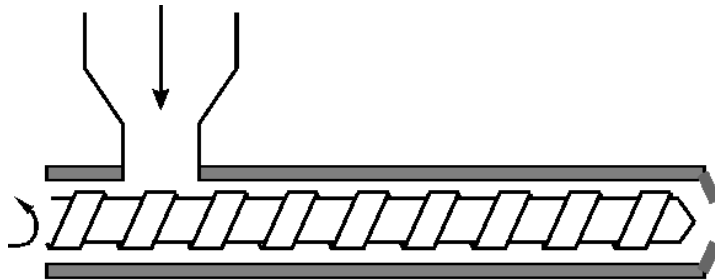


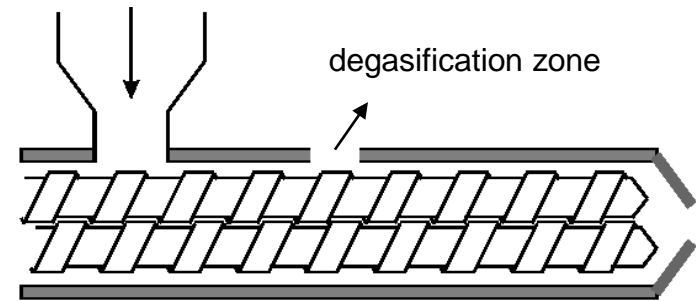
Process analysis using multivariate regression models exemplified by WPC processing with a single-screw extruder

# Motivation


Single-screw extruder vs. Twin-screw extruder



source: <http://www.polymerprocessing.com/>



- + lower costs of acquisition and production
- + flexible production of small profiles
- no degasification zones
- fewer capabilities for homogenisation and compression of melted mass



WPC processing  
and  
data acquisition

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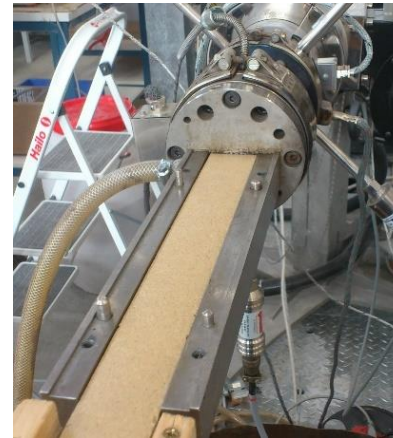
# WPC processing



50% softwood flour,  
45% PVC dry blend,  
5% lubricant



**Dry-air dryer**  
Wittmann Drymax  
Aton F120;  
110 °C



**Single-screw extruder**  
Extrunet ECE-42

**Twin-screw extruder**  
Cincinnati Milacron Titan 58



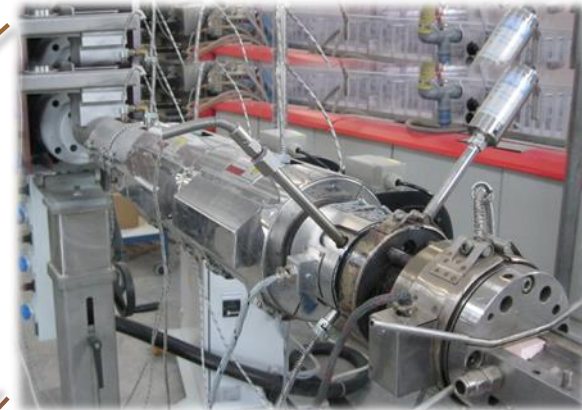
**WPC test profile**  
rectangular shape



# Data acquisition

## Consistently recorded machining parameters:

- temperature in 4 cylinder zones, adapter, tool, melted mass
- pressure in melted mass at 3 positions
- load of the extruder



data logger



Experimental design  
and  
data analysis

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# Single-screw extrusion

## **Design of experiments (general factorial design):**

- moisture content (MC): 0% – 1%
- screw speed: 10 RPM – 60 RPM
- boundary values determined in pre-tests
- 18 runs in total

## **Data analysis:**

- multiple linear regression & ANOVA
- variable selection (interval PLS)
- partial least squares regression (PLSR)
- leave one-out cross validation

# Twin-screw extrusion

## Design of experiments:

- moisture content (MC): 5.4%
- screw speed: 6 RPM
- 1 run as reference

## Data acquisition:

- raw material moisture content
- mechanical and physical properties of profiles





Results and discussion

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# WPC - profiles



0 % MC; 10 rpm

**“dry & slow”**

0.5 % MC; 35 rpm

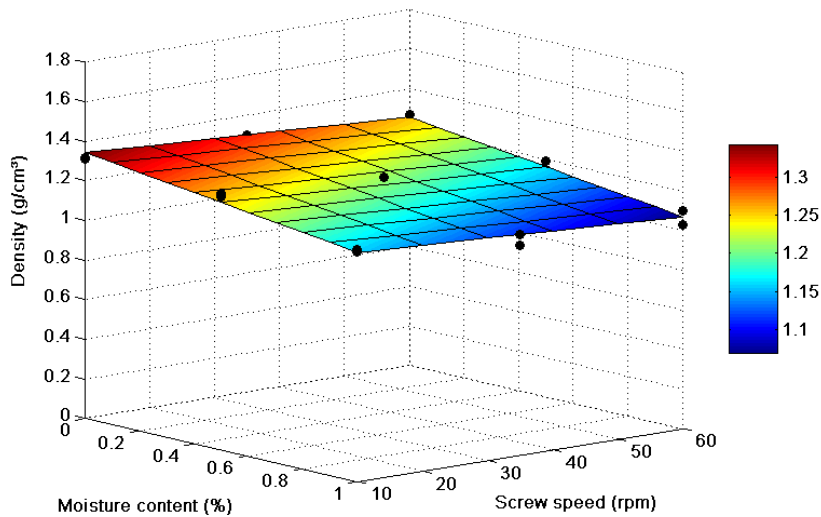
**“middle point”**

1% MC; 60 rpm

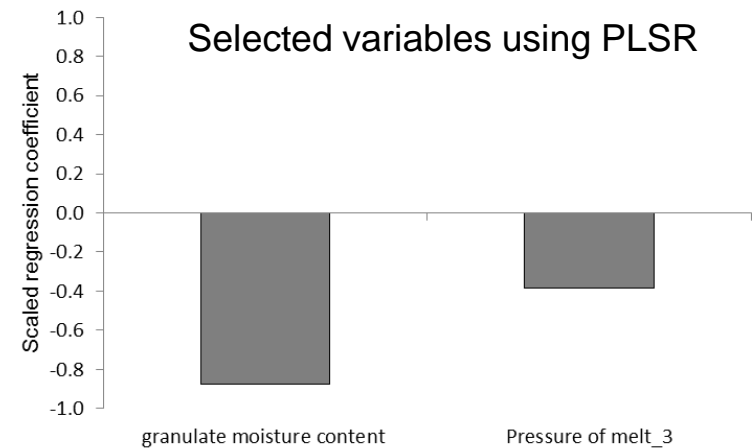
**“humid & fast”**

→ Increased moisture content of WPC granulate resulted in open edges and air pockets within the profiles

# Density of the profiles



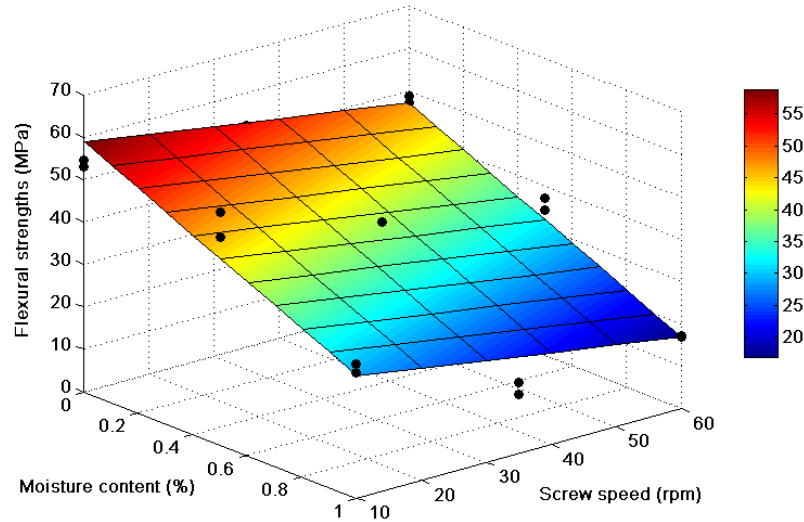
$R^2_{CV} = 91\%$  ; no. of latent variables = 1



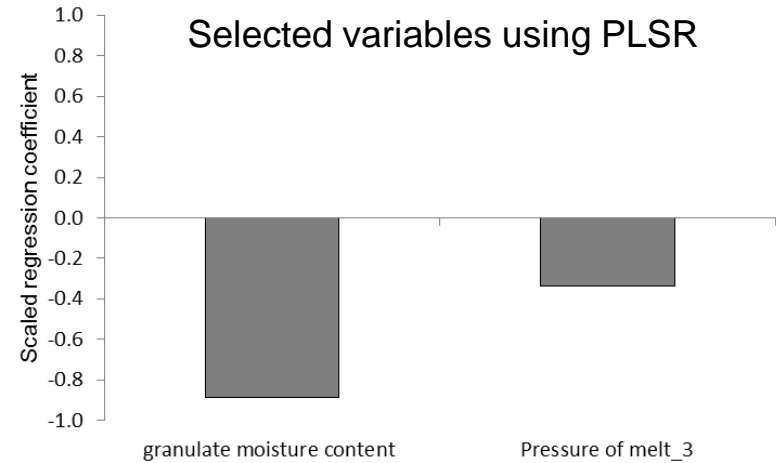
**Negative influence**

- “slow & dry”:  $1.32 \text{ g cm}^{-3}$
  - “fast & humid”:  $1.03 \text{ g cm}^{-3}$
- ↓ - 20%

# Flexural strength



$R^2_{CV} = 90\%$  ; no. of latent variables = 1



**Negative influence**

- “slow & dry”: 54.54 MPa
- “fast & humid”: 16.95 MPa

↓  
**- 69%**



# Single-screw vs. Twin-screw extrusion

Variant	Density (g cm <sup>-3</sup> )		Flexural strength (MPa)		Water uptake (%)	
	mean	std	mean	std	mean	std
Profile twin-screw	1.37	0.01	74.80	3.72	0.98	0.06
Profile single-screw (0% MC; 10 rpm)	1.32	0.01	54.54	1.83	1.64	0.08



- 3.6%



- 27%



+ 67%



Conclusion and outlook

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## Conclusion

- extruding PVC based WPC on single-screw was feasible
- best results with absolutely dry granulate
- screw speed should be low
- reliable models → reasonable interpretation possible

## Outlook

- detailed analysis of characterized  $\mu$ CT images
- new experiments with higher variation in process variables
- optimisation of extrusion parameters based on PLSR results
- optimisation of the screw geometry to improve the homogenisation of melted mass

# Thank you for your attention!

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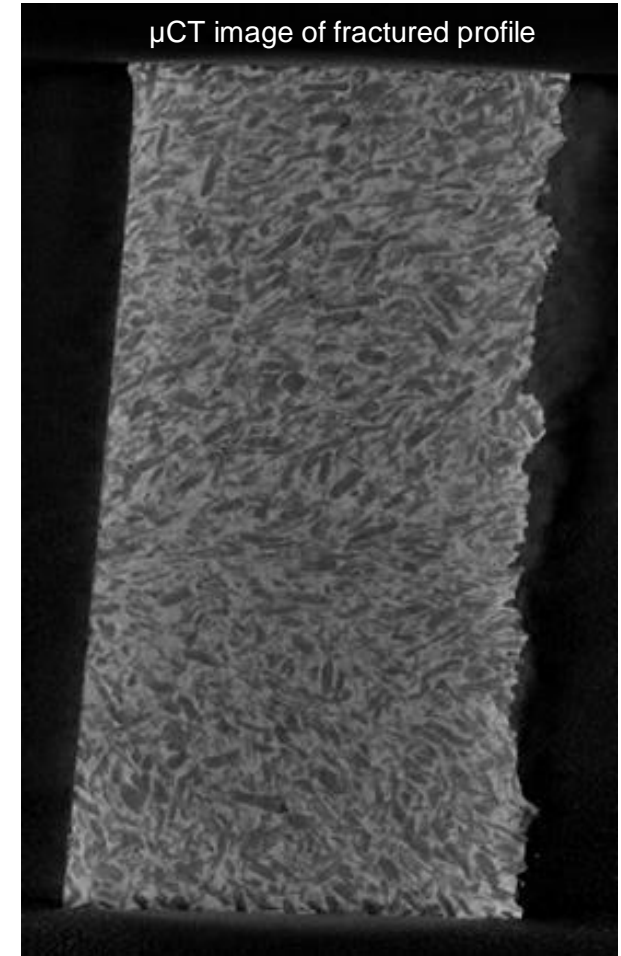
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# References

- JIANG H and KAMDEN DP (2004): Development of Poly(vinyl chloride)/Wood Composites. A Literature Review: Journal of vinyl & additive technology 10 (2): 59-69
- RIEGLER M, SYKACEK E and WIMMER R (2015): Processibility of wood-plastic composites on a single-screw extruder: InWood2015: Innovations in wood materials and processes, Brno, Czech Republic, 19–22 May 2015
- ROWELL RM, SANADI AR, CAULFIELD DF and JACOBSEN RE (1997): Utilization of Natural Fibers in Plastic Composites: Problems and Opportunities In: Lignocellulosic-Plastics Composites: 23-51
- WOLCOTT MP and ENGLUND KA (1999): Technology Review of Wood-Plastic Composites: In: 33rd International Particleboard/ Composite Materials Symposium: 103-111