

Data Description

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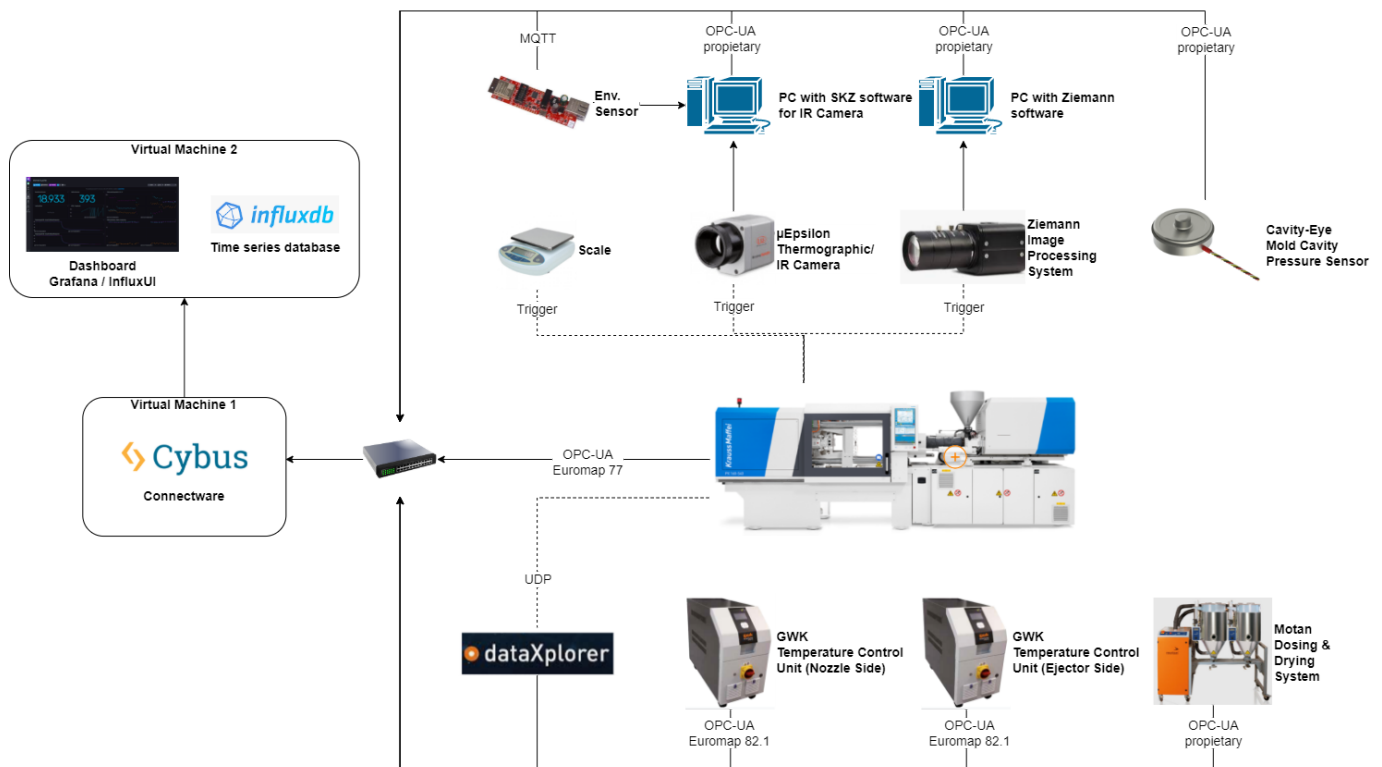
Overview

The data was collected during the research project 'ProBayes' conducted by SKZ (German Plastics Center) and Fraunhofer IPA from 2021 to 2023. This dataset was recorded in November 2022 and represents a Design of Experiment following a D-optimal pattern. An injection moulding machine (KraussMaffei 160-750PX) was equipped with peripheral devices and quality control devices, as you can see in the following figure. The part manufactured with the injection molding machine is called 'warpage shell' (~ Verzugsschale). It is used because it allows to easily reproduce warpage and shows very well the effect of different temperatures on the geometry. It was produced with polypropylene (Borealis HE125MO). The data from all different data sources were combined into one PARQUET file, where each row holds the data of one part / cycle. Each part can be identified using the unique MachineCycleID.

Hard facts:

- 303 injection moulded parts (28 experimental points)
- 9 datasources
- 396 features per part / injection molding cycle

The following figure shows all peripheral devices centered around the injection moulding machine:



Parameter Naming Convention

All parameters are described via a prefix and a parameter name. The prefix gives a hint at the data source as can be seen in the following table:

Data Source	Prefix	Explanation	Examples
Quality table	QUA	Cycle-based single values such as pressure or temperature values	QUA_CushionVolume
EUROMAP77	E77	Cycle-based single values such as pressure or temperature values	E77_CavityPressureMaximum
DataXplorer	DXP	Time series data from the KraussMaffei injection molding machine, e.g. pressure curves	DXP_Inj1PrsAct
Temperature Control Unit Ejector Side	TCE	Time series data from the temperature control unit for the ejector side	TCE_TemperatureReturnLine
Temperature Control Unit Nozzle Side	TCN	Time series data from the temperature control unit for the nozzle side	TCN_TemperatureReturnLine
Drying system	DRY	A drying system is used to dry the material before the injection molding process	DRY_HT101_acTempReturnAir
Dosing system	DOS	The dosing system doses the plastic granules for the injection molding machine	DOS_acComp1DosRate

Data Source	Prefix	Explanation	Examples
Image processing system / Computer Vision	CV	Computer Vision to detect geometrical dimensions of the plastic part	CV_Width1
Thermal / IR camera	IR	Infrared camera to detect the surface temperature of the plastic part after it is ejected	IR_Image1Name
Meta data	MET	Meta information such as cycle id, experiment number, timestamp etc.	MET_JobCycleID
Scale	SCA	A Scale is used to weigh the manufactured plastic parts	SCA_PartWeight
Environmental sensor	ENV	Environmental sensor detects the air temperature and humidity	ENV_AirTemperature
Manual visual defect inspection	LBL	Surface defects of the plastic part are labels	LBL_SinkMarks
Calculated Features	CALC	Features calculated from other features e.g. extracted from timeseries	CALC_DosedWeight

Data Sources

Meta Data (MET)

The meta data includes, for example, the injection molding cycle number or the name of the respective test series. All associated parameters are listed below.

Feature	Explanation	Unit	dtype
MET_JobCycleID	Consecutive job cycle number starting again at 1 for each test day	-	int
MET_MachineCycleID	Consecutive machine cycle number that is never reset	-	int
MET_ExperimentNumber	For all cycles with the same experiment number (e.g. A16) identical parameter settings were used	-	str
MET_TimeCycleStart	Starting time of the respective injection molding cycle	-	datetime
MET_TimeCycleEnd	End time of the respective injection molding cycle	-	datetime
MET_MaterialName	Name of the plastic material used for the tests	-	str
MET_MaterialMoisture	Moisture content of the plastic material	%	float

Environmental Sensor (ENV)

The temperature and humidity sensor (type DHT22) was placed in proximity to the IR camera.

Feature	Explanation	Unit	dtype
ENV_AirTemperature	Temperature of the air in the production hall close to the injection molding machine	°C	float
ENV_AirHumidity	Relative humidity of the air in the production hall close to the injection molding machine	%	float

Thermal / IR Camera (IR)

A robot removes the finished parts from the mold and positions them in front of an infrared camera to take photos (thermographic images) of the entire part at 15 second intervals. Two images per part were taken during the November 2022 test days.

Feature	Explanation	Unit	dtype
IR_Image1Name	File name of the first thermographic image of a part	-	str
IR_Image2Name	File name of the second thermographic image of a part	-	str

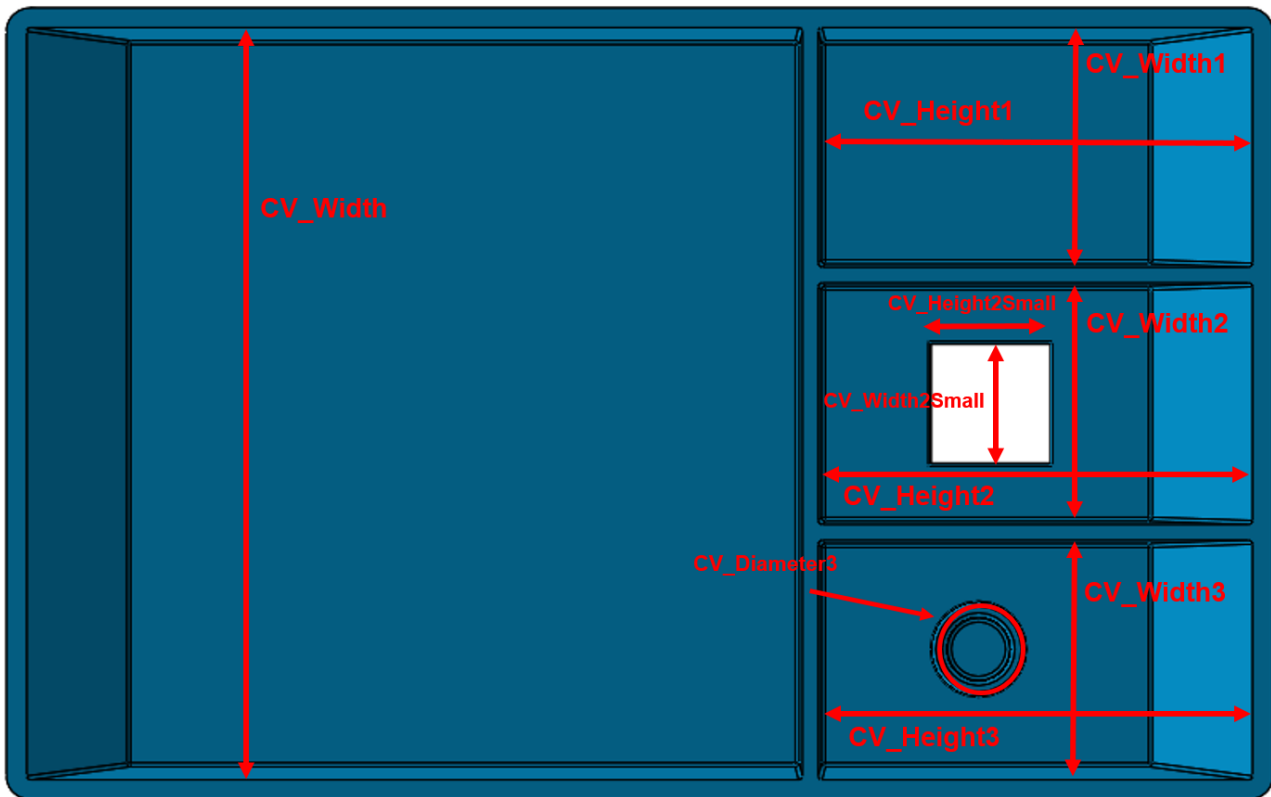
Image Processing System / Computer Vision (CV)

After the thermal camera has taken three photos the robot moves the part in front of a standard camera. This camera then takes close-up images of each of the three sections in the upper area of the injection molded part. Subsequently, computer vision is used to measure the distances between certain edges. The extracted features are listed below and can also be seen in the figure below.

Feature	Explanation	Unit	dtype
CV_Image1Name	File name of the image of the first (left) part area	-	str
CV_Image2Name	File name of the image of the first (mid) part area	-	str
CV_Image3Name	File name of the image of the first (right) part area	-	str
CV_Height1	Height of the first section	mm	float
CV_Width1	Width of the first section	mm	float
CV_Height2	Height of the second section	mm	float
CV_Width2	Width of the second section	mm	float
CV_Height2Small	Height of the quadratic recess in the second section	mm	float
CV_Width2Small	Width of the quadratic recess in the second section	mm	float
CV_Height3	Height of the third section	mm	float
CV_Width3	Width of the third section	mm	float
CV_Diameter3	Diameter of the dome in the third section	mm	float
CV_Warpage	Key indicator to describe the total warpage of the component	mm	float
CV_Width	Total width of the component measured in the lower area	mm	float

The parameter "CV_Warpage" is intended to describe the total warpage of the component and is calculated by the following equation:

$$CV_Warpage = |CV_Width1(target) - CV_Width1(actual)| + |CV_Width2(target) - CV_Width2(actual)| + |CV_Width3(target) - CV_Width3(actual)|.$$



DataXplorer (DXP)

The dataXplorer is a preconfigured data storage device for automatic recording of sensor and control data of an injection molding machine, in whose control cabinet the hardware and software are integrated. The naming of the parameters was done by the machine manufacturer KraussMaffei. A list to look up the parameter names (German and English) is appended to this data description.

Values are recorded for the parameters at a frequency of 0.005 seconds, i.e. the data are available here as time series. Since each row in the data set corresponds to one injection molding cycle, the time series associated with the various parameters were each packed into an array and stored in a cell. In addition to the classic parameters such as pressures or temperatures, there are also various triggers. These triggers are either true (= 1) or false (= 0). All the different triggers are listed below.

Feature	Explanation (English)	Explanation (German)
DXP_TrigClpCls	True while the clamping unit is closed	Wahr während Schließe öffnet
DXP_TrigClpOpn	True while the clamping unit is opened	Wahr während Schließe schließt
DXP_TrigInj1	True during the injection phase	Wahr während der Einspritzphase
DXP_TrigHld1	True during the holding pressure phase	Wahr während der Nachdruckphase

Feature	Explanation (English)	Explanation (German)
DXP_TrigPlst1	True during the plastification of the injection unit	Wahr während Einspritzeinheit plastifiziert
DXP_TrigInj1Dcmp1	True while decompression 1 of injection unit	Wahr während Dekompression 1 Einspritzeinheit
DXP_TrigInj1Dcmp2	True while decompression 2 of injection unit	Wahr während Dekompression 2 Einspritzeinheit
DXP_TrigCool	True during the cooling phase	Wahr während Kühlphase
DXP_TrigClpCfr	True while clamping force is released	Wahr während Schließe Schließkraftabbau
DXP_TrigClpCfb	True while clamping force is built up	Wahr während Schließe Schließkraftaufbau
DXP_TrigEje1Fwd	True while the ejector is moved forwards	Wahr während Auswerfer vorfahren
DXP_TrigEje1Rew	True while the ejector is moved rearwards	Wahr während Auswerfer zurückfahren
DXP_TrigInju1Fwd	True while the injection unit is moved forwards	Wahr während Einspritzeinheit vorfährt
DXP_TrigInju1Rew	True while the injection unit is moved rearwards	Wahr während Einspritzeinheit zurückfährt

Temperature Control Units (TCE/TCN)

Temperature control units are used to control the temperature of the injection mold. An injection mold consists of two halves, one on the ejector side, the other on the nozzle side. A separate temperature control unit is used for each mold half (TCE = temperature control unit ejector side, TCN = temperature control unit nozzle side). The data is acquired using EUROMAP 82.1, which is equivalent to OPC-UA Companion Specification 40082-1. Check out the documentation [here](#) for more details about the parameters. The data here are available as time series again, that have been packed into arrays. Cycle-wise mean values were determined for each parameter. These are stored in the data set as float values and end with the suffix "Mean". Some example parameters are listed in the table below.

Feature	Explanation	Unit	dtype
TCN_TemperatureMainLine	Course of the actual temperature of the cooling medium in the supply line to the mold on the nozzle side during one cycle	°C	object
TCN_TemperatureMainLineMean	Mean temperature of the cooling medium in the supply line to the mold on the nozzle side during one cycle	°C	float

Feature	Explanation	Unit	dtype
TCE_TemperatureMainLine	Course of the actual temperature of the cooling medium in the supply line to the mold on the ejector side during one cycle	°C	object
TCE_TemperatureMainLineMean	Mean temperature of the cooling medium in the supply line to the mold on the ejector side during one cycle	°C	float

Quality table (QUA)

The so-called quality table can be exported from KraussMaffei injection molding machines and contains cycle-related individual values, e.g. temperature or pressure values. Some of the parameters it contains overlap with the EUROMAP77 parameters.

Feature	Explanation	Unit	dtype
QUA_CycleTime	Duration of the injection molding cycle	s	float
QUA_InjectionTime	Duration of the injection phase	s	float
QUA_CylinderTemperature01	Temperature of the cylinder at position 1	°C	float
QUA_InjectionPressureMax	Maximum injection pressure	bar	float
QUA_CavityPressureMax	Maximum cavity pressure	bar	float

EUROMAP77 (E77)

The EUROMAP77 is equivalent to the OPC-UA 40077 Companion Specification. Check out the documentation [here](#) for more details about the parameters. Also the EUROMAP77 is built on top of EUROMAP83, so some parameter descriptions can be found [here](#). Some example parameters are listed below. All parameters with prefix E77 are single values, i.e. there is exactly one value for each cycle. Some of the E77 parameters are identical or very similar to the QUA parameters, but the names may differ slightly.

Feature	Unit	Explanation	dtype
E77_BarrelTemperatureZone1	°C	Temperature of the barrel / cylinder at position 1	float
E77_CavityPressureMaximum	bar	Maximum pressure inside the cavity	float
E77_DosingTime	s	Duration of the dosing phase	float

Dosing (DOS) and Drying System (DRY)

The drying and dosing system from [Motan](#) consists of a dry air generator, two drying hoppers, a dosing device and a moisture measuring device. They communicate internally and share their data via a proprietary OPC-UA server, since there is no OPC-UA Companion Specification for this yet (EUROMAP86 is still under development). Dosing related parameters share the prefix DOS and drying related parameters the prefix DRY. Just like with the dataXplorer and temperature control unit data the dosing and drying data are available as time series data and stored in arrays.

Scale (SCA)

Before weighing, the sprue is manually clipped off the cooled plastic part using pliers. The part is then placed manually on a scale, the weight is read off and written in a table.

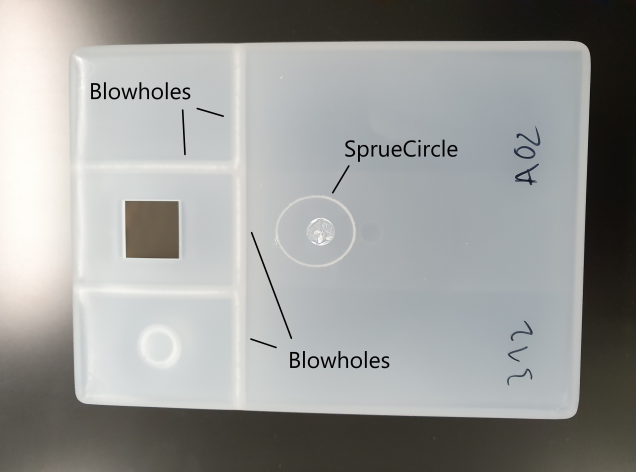

Feature	Unit	Explanation	dtype
SCA_PartWeight	g	Weight of the manufactured plastic part	float

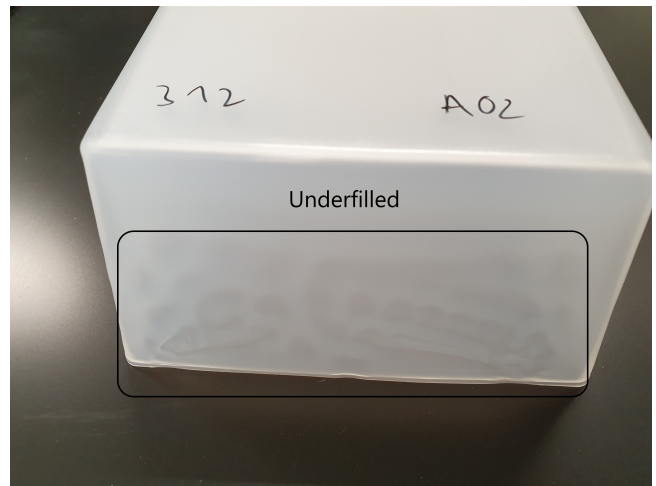
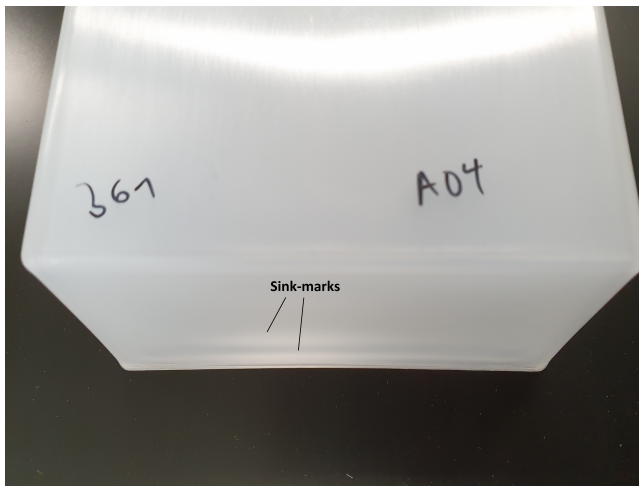
Manual Visual Defect Inspection (LBL)

After weighing the parts, they were visually inspected to identify typical defect types. A list of the possible defects is given below.

Feature	Explanation
LBL_SinkMarks	("Einfallstellen") - Defect description
LBL_SprueCircle	("Kreis um Anguss")
LBL_Underfilled	("Unterfüllt") - Defect description
LBL_OldGranulate	("Altes Granulat") - Granulate from previous product
LBL_StreaksLevel1	("Schlieren Stufe 1")
LBL_StreaksLevel2	("Schlieren Stufe 2")
LBL_StreaksLevel3	("Schlieren Stufe 3")
LBL_NOK	("Teil ist n.i.O.") - Part is not OK

LBL_NOK is basically a summarization of the two most drastic defect types (LBL_Underfilled and LBL_SinkMarks). As soon as at least one of them is present (= 1), LBL_NOK is "1" as well which means that the part is not OK (= NOK). If none of these two defects is present its value is 0 meaning it is OK. Some of the component defects can be seen in the following pictures.

<p>LBL_SprueCircle</p> 	<p>LBL_StreaksLevel3</p> 
<p>LBL_SinkMarks</p>	<p>LBL_Underfilled</p>



LBL_OldGranulate



Machine settings (SET)

All the machine settings changed in the experimental trials (see tables [here](#)) are included in the data set as parameters with the prefix "SET_" (see the following table) and contain the target values. The actual values may differ slightly and are included in the data set under other parameter designations (see table [here](#)).

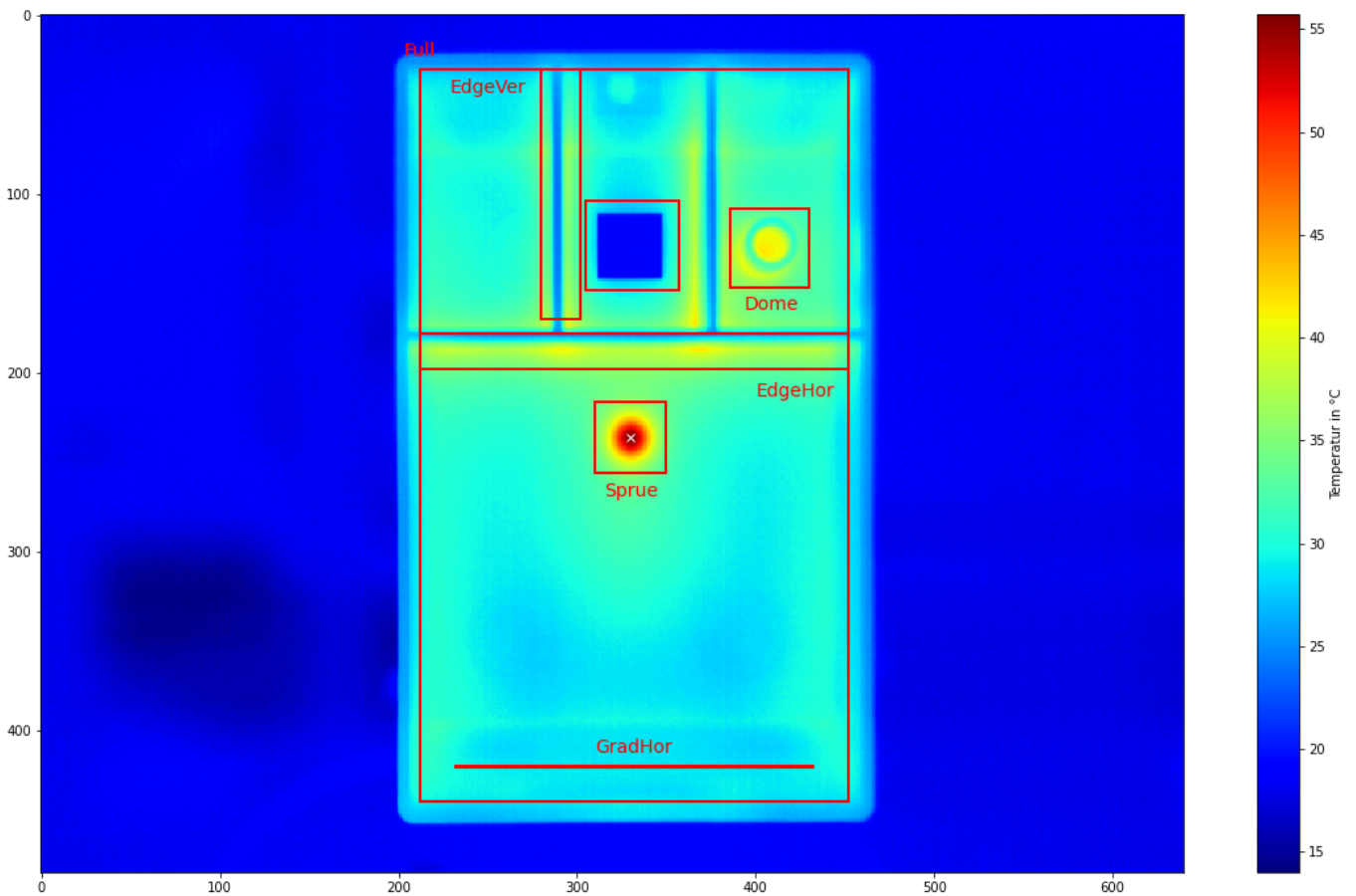
Feature	Explanation	Unit	dtype
SET_CylinderTemperature	Temperature of a specific cylinder zone (the temperatures of the other zones were changed in the same ratio)	°C	float
SET_ToolTemperature	Temperature of the tool/mold	°C	float
SET_HoldingPressure1	Holding pressure in first phase	bar	float

Feature	Explanation	Unit	dtype
SET_HoldingPressure2	Holding pressure in second phase	bar	float

Extracted Features

Thermal camera

The thermal camera images were analyzed to identify areas where temperatures varied widely between different test series and components. As a result, the mean temperatures of four areas are extracted: sprue, dome, horizontal edge and vertical edge (see figure below). In addition, the average temperature of the complete component is extracted, excluding the area around the cutout.



The following table lists some of the extracted features including a short description. Each of these features is extracted for both images of each component, identifiable by "Img1" and "Img2" respectively.

Feature	Explanation	Unit	dtype
IR_Img1TempSprue	Average temperature of the area around the sprue in the first image	°C	float
IR_Img2TempSprue	Average temperature of the area around the sprue in the second image	°C	float
IR_Img1TempDome	Average temperature of the area around the dome in the first image	°C	float

Feature	Explanation	Unit	dtype
IR_Img1TempEdgeHor	Average temperature of the area around the horizontal edge in the first image	°C	float
IR_Img1TempEdgeVer	Average temperature of the area around the vertical edge in the first image	°C	float
IR_Img1TempFull	Average temperature of the complete component in the first image	°C	float
IR_Img1TempGradHorStd	Standard deviation of the gradient of the temperature profile in the first image	°C	float
IR_Img1TempGradHorRng	Range from min to max value of the gradient of the temperature profile in the first image	°C	float
IR_Img1TempHorStd	Standard deviation of the temperature profile in the first image	°C	float
IR_Img1TempHorRng	Range from min to max value of the temperature profile in the first image	°C	float

In addition, a reference image was subtracted from all images taken during the experiments on 07.12.2021 (material used: PP). This reference image is an averaged image from the first images of each component of the test series "Z01" (central point). From the generated difference images, the same features as in the original images were then extracted again, indicated by the suffix "Diff" (see table below for some examples).

Feature	Explanation	Unit	dtype
IR_Img1TempSprueDiff	Average temperature of the area around the sprue in the first difference image	°C	float
IR_Img2TempSprueDiff	Average temperature of the area around the sprue in the second difference image	°C	float

Dosed Weight

From the position of the screw (DXP_Inj1PosAct), we can extract the volume of the injected melt (screw position change from start of injection phase until end of holding phase) and of the volume of the dosed melt (screw position change during dosing phase) for the next shot. To calculate a weight from the volume, the density is needed which itself depends on temperature and on pressure. This relationship is described by Tait's model. Ultimately, the weight of the dosed melt has been calculated (for Polypropylen only):

Feature	Explanation	Unit	dtype
CALC_InjectionStroke	screw position change from start of injection phase until end of holding phase	mm	float
CALC_DosedWeight	Weight of the dosed melt calculated by applying Tait's model to dosed volume	g	float

Feature	Explanation	Unit	dtype
CALC_DosingStroke	screw position change during dosing phase	mm	float

Datasets

Structure

Each row in the dataset represents one injection molding cycle and thus one produced part. The columns contain the various features mentioned above. In the case of numerical parameters, these are either stored as single values (i.e. a single number in a cell) or, in the case of time series, as an array in a cell. This means that the arrays each contain all the values of the time series associated with a particular cycle.

Data from November 2022 (Material: PP)

The November 2022 experiments were conducted based on a d-optimal experimental design.

Experiment Number	Cylinder Temperature [°C]	Tool Temperature [°C]	Injection Speed [ccm/s]	Holding Pressure [bar]
A01-H	220	30	40	150
A02-H	220	30	40	200
A03-H	220	30	40	300
A04-H	220	30	83	250
A05-H	220	30	105	150
A06-H	220	30	105	300
A07-H	220	45	62	300
A08-H	220	45	83	150
A09-H	220	60	40	250
A10-H	220	60	40	300
A11-H	220	60	62	150
A12-H	220	60	105	200
A13-H	220	60	105	300
A14-H	240	30	62	250
A15-H	240	45	40	200
A16-H	240	60	83	150
A17-H	240	60	105	300
A18-H	260	30	40	150

Experiment Number	Cylinder Temperature [°C]	Tool Temperature [°C]	Injection Speed [ccm/s]	Holding Pressure [bar]
A19-H	260	30	40	300
A20-H	260	30	83	200
A21-H	260	30	105	150
A22-H	260	30	105	300
A23-H	260	45	105	250
A24-H	260	60	40	150
A25-H	260	60	40	300
A26-H	260	60	62	200
A27-H	260	60	83	300
A28-H	260	60	105	150

Target and actual values in the dataset

The data set contains both the target values of the individual parameters from the test plans (listed in the tables above) and the actual measured values. The following table provides an overview of the corresponding parameters in the data set.

Parameter in experimental plan	Corresponding parameter (target values)	Corresponding parameter (actual values)
Cylinder Temperature [°C]	SET_CylinderTemperature	QUA_CylinderTemperature11
Tool Temperature [°C]	SET_ToolTemperature	TCE_TemperatureMainLineMean
Injection Speed [ccm/s]	SET_InjectionSpeed	E77_InjectionSpeedAverage
Holding Pressure [bar]	SET_HoldingPressure	DXP_HoldingPressure1