Industrial investigations of fibre optical sensor instrumented thick slab caster mould

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Motivation

- Reduce or avoid corner cracks
- Optimize mould geometry
- Control the beginning solidification
- Extended knowledge on physical phenomena occurring in the mould

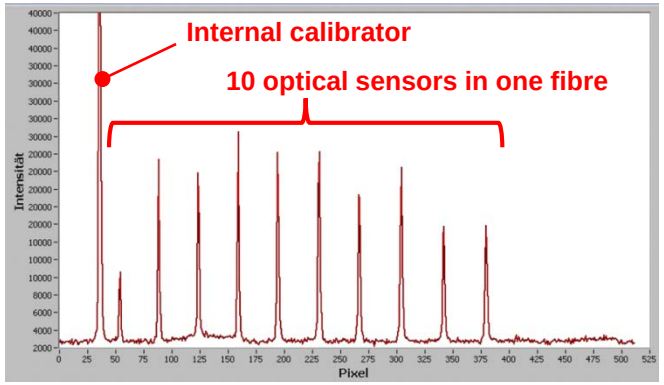
Principle: fibre optical temperature measurement

New tools to optimize process control

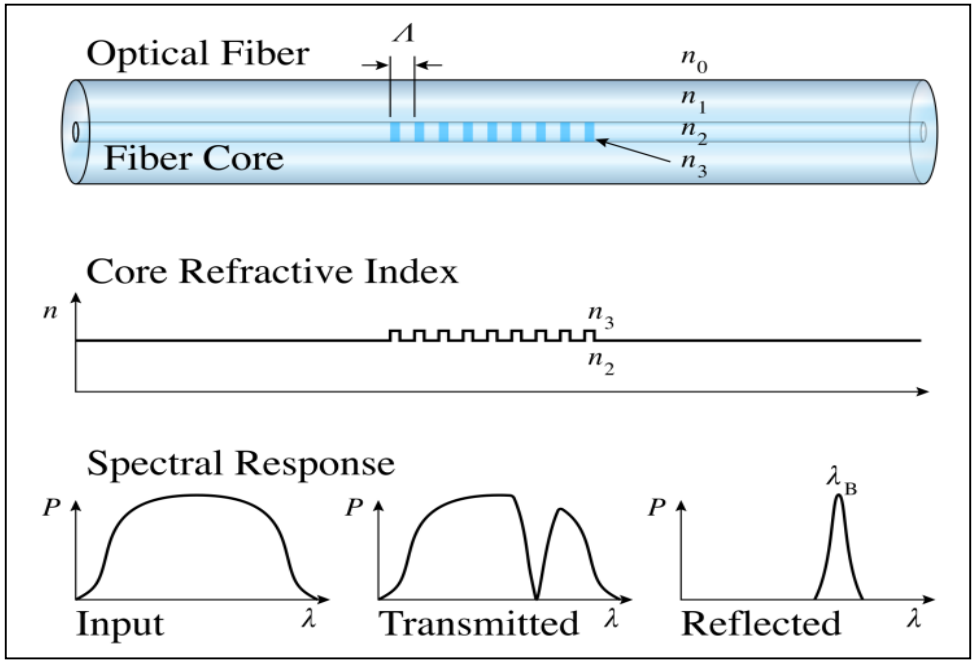
Fibre Bragg grating as sensing element

Reflected wavelength proportional to

- Strain
- Temperature



Example spectrum of user sensor array



Source: Matthias Krüger, Wikipedia Commons

Schematic depiction of a single fibre optical sensor

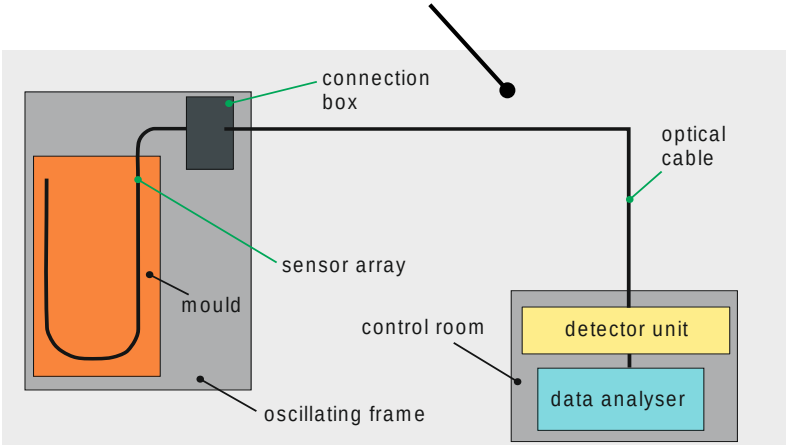
Monitoring the mould temperature by using fibre-optical-sensors

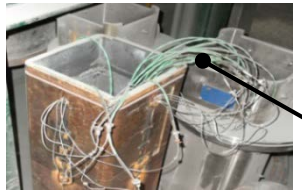
Advantage of Fibre-Optical-Temperature-Sensors (FOTS)

FOTS

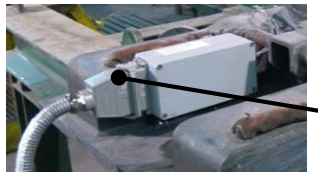
- No influences by electro-magnetic fields
- No or less influence of water flow
- Only one access point per mould plate
- Geometrically free positioning up to 20 temperature sensors in one fibre
- Multiple usage also possible

Principle structure and components of the used FOTS-system





Cable bundle
15 thermocouple



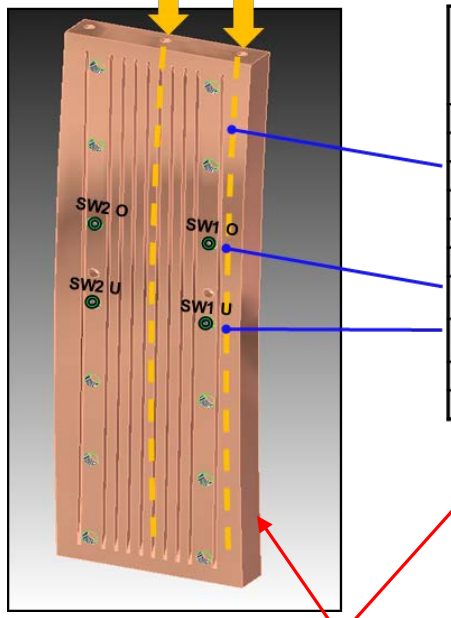
FOTS cabling:
application with
40 measuring points

*Thermocouple (TC)

Data of continuous SZFG caster No. 4

- CC type: bow type continuous casting machine with large radius (necessary for 350 mm thick slabs/ no bending of the strand shell)
- One strand
- Casting formats:
  - slab thickness 250/350 mm
  - slab width 1.100 – 2.600 mm (cold)
  - slab length 4.2 – 12.4 m
- Max. casting speed: about 1.35 m/min (low carbon 250 mm thick)
  about 0.65 m/min (steel plate 350 mm thick)
- Compact mould length: 900 mm
- Resonance mould oscillator
- Adjustable width => moving narrow faces

Installation at the caster

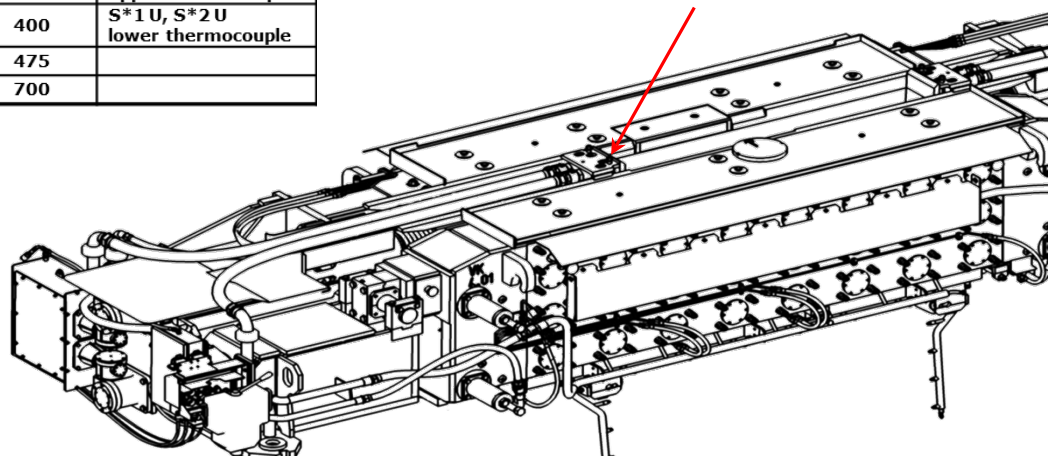


No	Distance from Upper Edge of Copper Plate in mm	Relative Distance to Meniscus in mm	Remark
1	40	-50	
2	65	-25	
3	90	0	meniscus
4	115	25	
5	140	50	
6	190	100	
7	240	150	S*1 O, S*2 O upper thermocouple
8	490	400	S*1 U, S*2 U lower thermocouple
9	565	475	
10	790	700	

Location of the FOTS at the narrow face

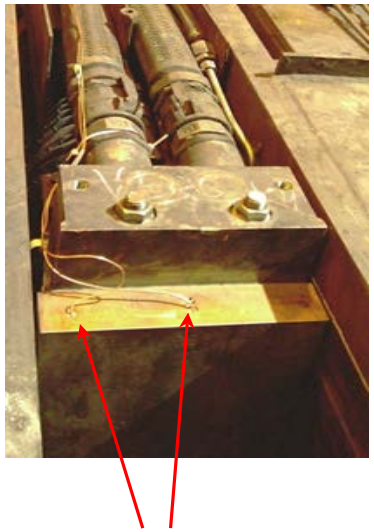
Two sensor arrays at one narrow face
- 10 temperature points along centre axis
- 10 temperature points in corner region

Instrumented narrow face located at the west side of the mould



Installation at the caster

Multi point FOTS installed at the narrow face of SZFG-caster



a) Installed narrow face with FOTS-arrays

b) FOTS-connector and flexible optical cable

c) Detector unit and analysis system

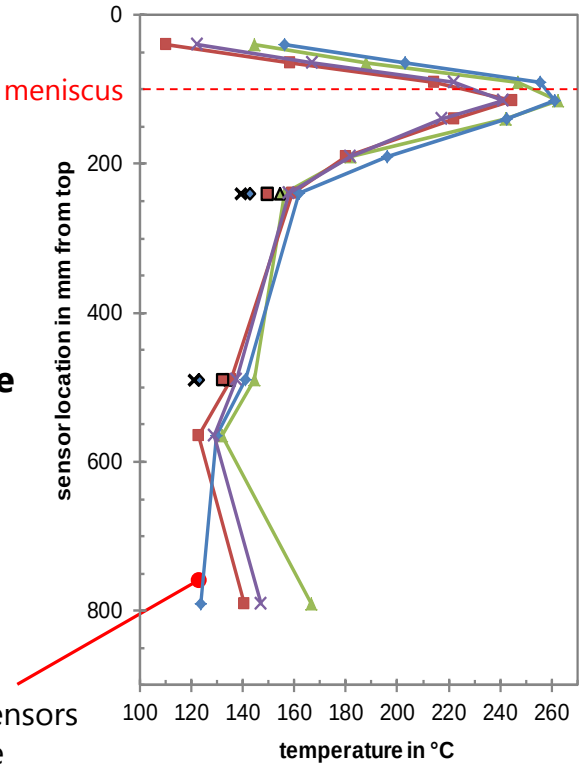
Images taken from a previous project (Transient, RFSR-CT-2009-00005)

Measurements - using standard narrow face

Mould wall temperatures along corner and centre axis

Mould wall temperatures along corner and centre axis for 2.6 and 1.6 meters width

- **Maximum temperatures 25 mm below the meniscus**
- **Temperatures at the corner generally lower than in the centre**
- **Indication of wrong taper adjustment while temperature increases at the mould end**



mean values: fibre-optical-sensors
thermocouple

		1	2	3	4
$(FOTS - TC)_{240}$	K	2	10	19	19
$(FOTS - TC)_{490}$	K	10	3	18	17
Gradient FOTS	K	11	24	21	20
Gradient TC	K	20	17	20	18

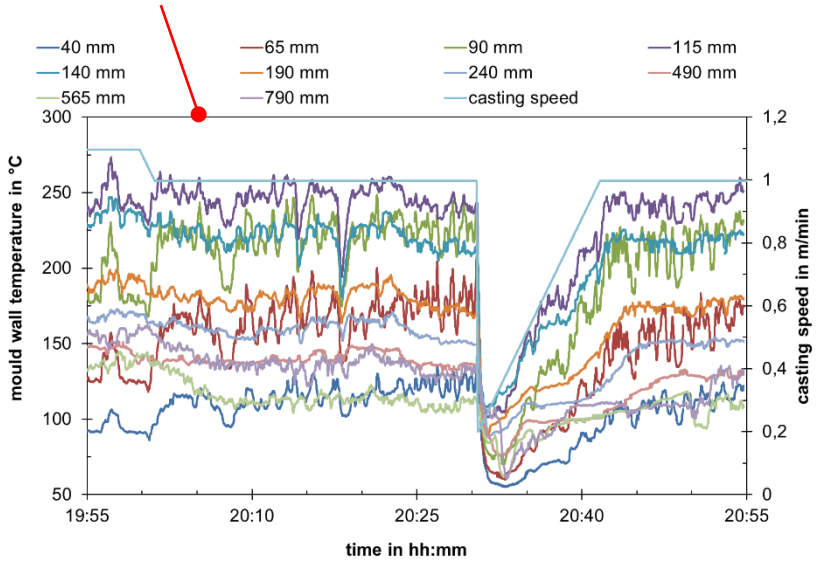
Casting conditions		1	2	3	4
set speed	m/min	0,99	0,99	1,06	1,06
real speed	m/min	1,02	1,02	1,00	1,00
width	m	2,60	2,60	1,60	1,60
productivity	t/min	5,37	5,37	3,30	3,30
DT	K	11	11	20	20
TG	K	9	9	0	0
heatflux	MJ/min	15	15	13	13
duration	hh:mm	01:01	01:01	00:10	0:10

No	FOTS	TC	Quality
1			RSt52_15_Nb_Ni(F) Center
2			RSt52_15_Nb_Ni(F) Corner
3			RSt52_15_Nb_Ti(F) Center
4		X	RSt52_15_Nb_Ti(F) Corner

Measurements - using standard narrow face

Results of Temperature Measurement during sticker alarm

Corner temperature of narrow face during sticker alarm

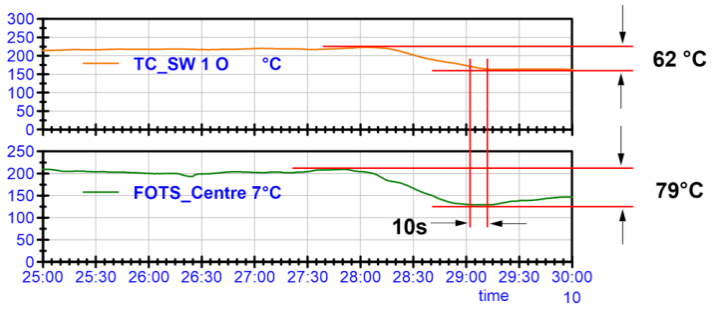


- Casting speed directly influences the mould wall temperatures
- Temperature maximum at 115 mm decreases 150 K during sticker alarm

Comparison TC versus FOTS
(same distance from top)

FOTS advantage up to:

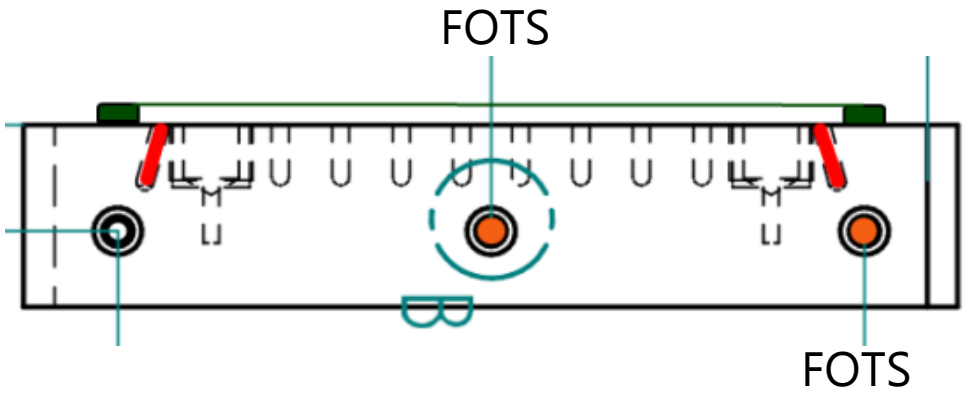
- **10 seconds additional reaction time**
- **17°C increased temperature dynamic**



Modification of the narrow face

Preparation of the mould to reduce cooling in the corner area

- Outer cooling channels filled up with resin (temperature stability up to 200°C)
- Sealing (temperature stability up to 250°C)
- Two FOTS-arrays on narrow side-west, centre line and corner area on the loose side (continuous operating temperature - up to 250°C)



Measurements - using modified narrow face

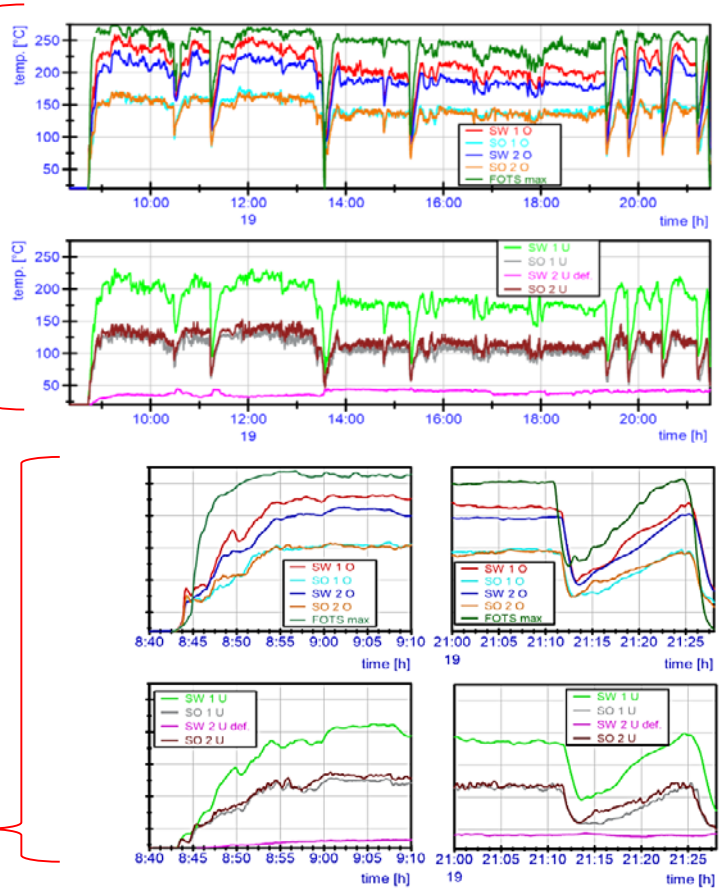
Results of plant trials with modified mould

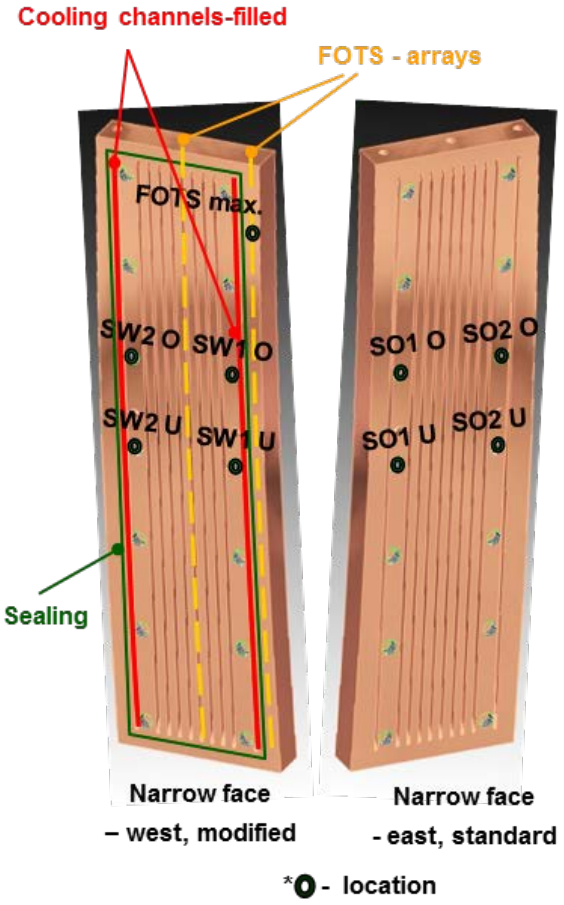
measurement campaign

- Temperatures on west-side (TC: SWxx) (modified) up to 70°C higher than on the east-side (TC: SOxx)
- Difference of about 20°C between loose side (TC: SW1-O) and fix side (TC: SW2-O) of the modified mould
- Temperature of corner (FOTSmax), 25 mm beneath the meniscus, rise up to more than 270°C

→ Cooling of the modified mould plate on the west-side clearly different from the one on the east-side

Detail: start casting - end of casting

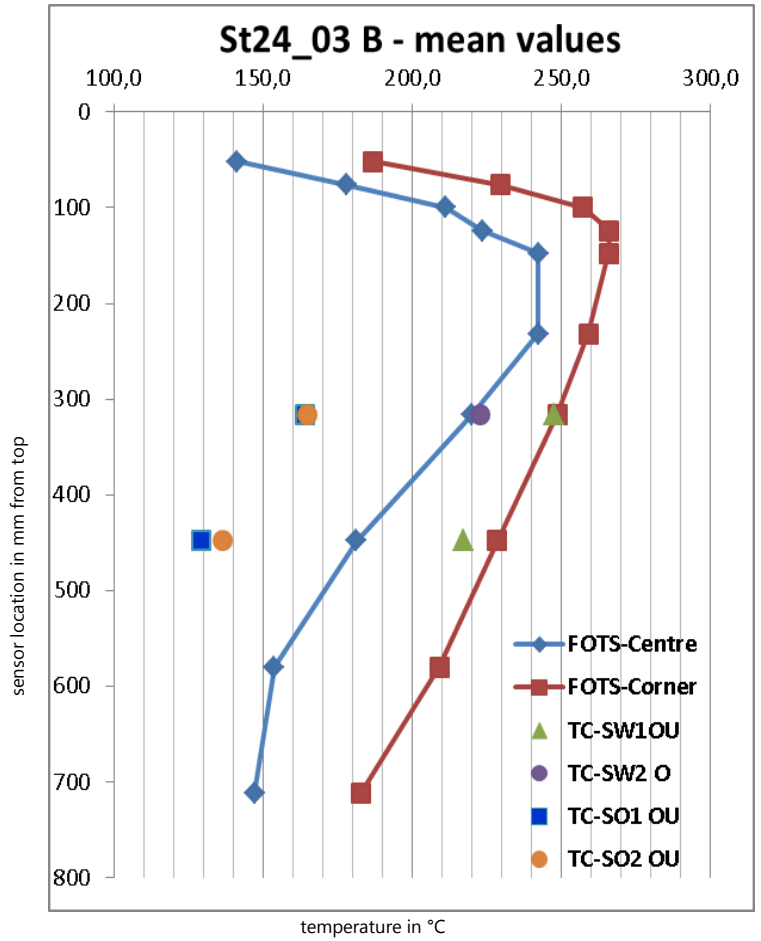




Measurements - using modified narrow face

Averaged temperatures along corner and centre axis for 1.82 meters width

- **Different behaviour compared to the one in the earlier trials**
- **Temperatures at the centre now lower than in the corner**
- **Temperatures at narrow face-west (TC: SWxx) (modified) clearly higher than at narrow face-east (TC: SOxx)**
- **Similar results for thermocouples and FOTS in similar locations (→ corner)**



Casting conditions:
Quality: ST24_03B
Width: 1820 mm
Speed: 0.9 m/min

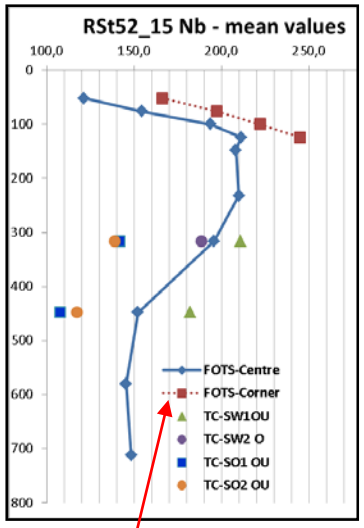
Temp. max.:
266 °C FOTS-Corner, pos. 4/5
242 °C FOTS-Centre, pos. 5/6

Deviation (FOTS-Corner/Centre):
mean = 39.3 °C
max. = 55.2 °C, sensor pos. 9
min. = 16.9 °C, sensor pos. 6

Modified narrow face - Trial results

FOTS defect and water leakage because of high temperature

Water leakage after a 19 hours period of working and 17 heats



Fibre „FOTS-Corner“: defect after 3.5 hours of working, caused by overheating

Leakage zone at the loose-side between copper plate and water box (length about 500 mm)

Sealing defects, caused by overheating

- No unusual defects or heat distortion at the copper plate after dismounting

Conclusion I

Fibre optical sensor system:

- Temperature results of FOTS comparable to thermocouples
- FOTS-System shows a higher resolution in space and time
- Operators are enabled to monitor the temperature profile and the area around the meniscus
- Alarm values for undesired casting situations (level changes, sticker e.g.) could be derived
- Temperature limitations must be taken into account

Conclusion II

Trials and results:

- Two measuring campaigns were successfully performed. One with the initial mould geometry and one with an adjusted mould geometry
- Explicit rise of temperature in corner area with modified mould
- Risk of water leakage increases

Thank you for your attention!

Questions?

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