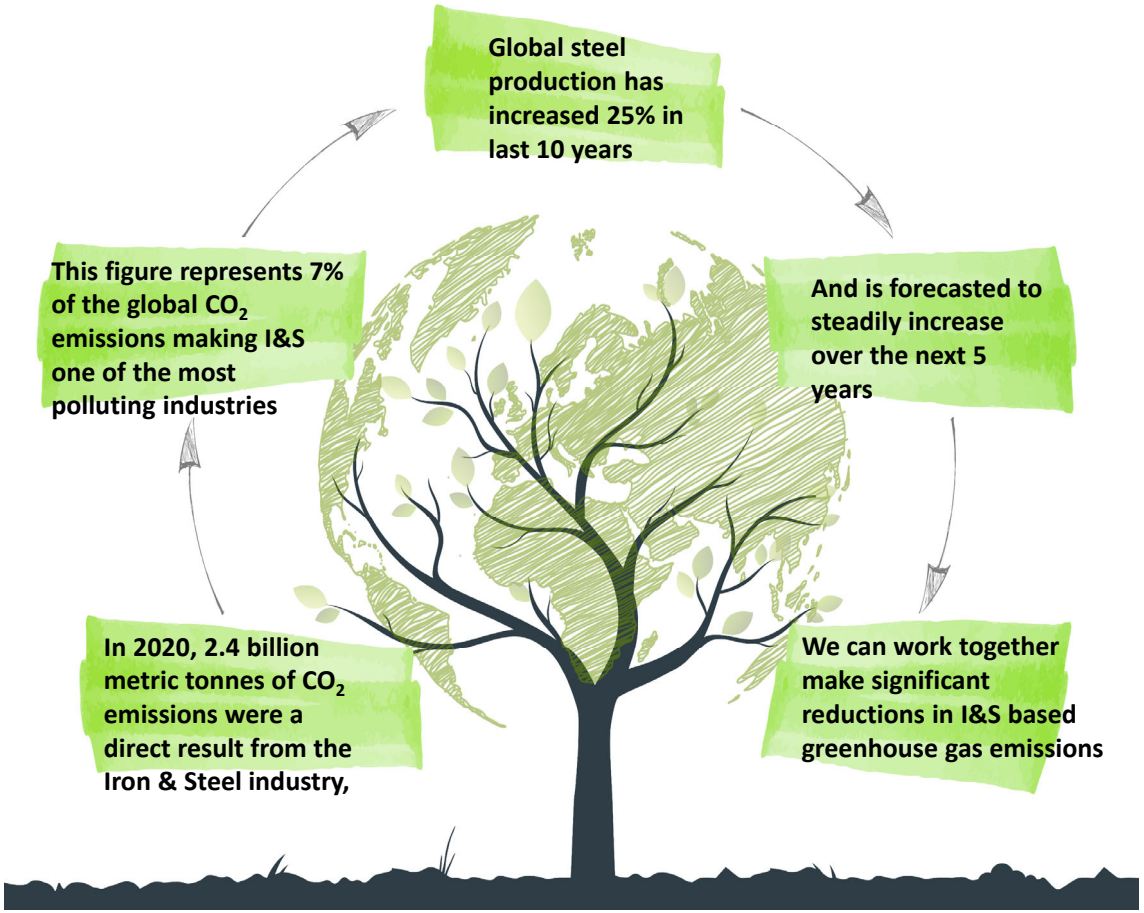
Sustained Engineering savings by Utilization of Enhanced Rear Insulation

How could we be more sustainable?

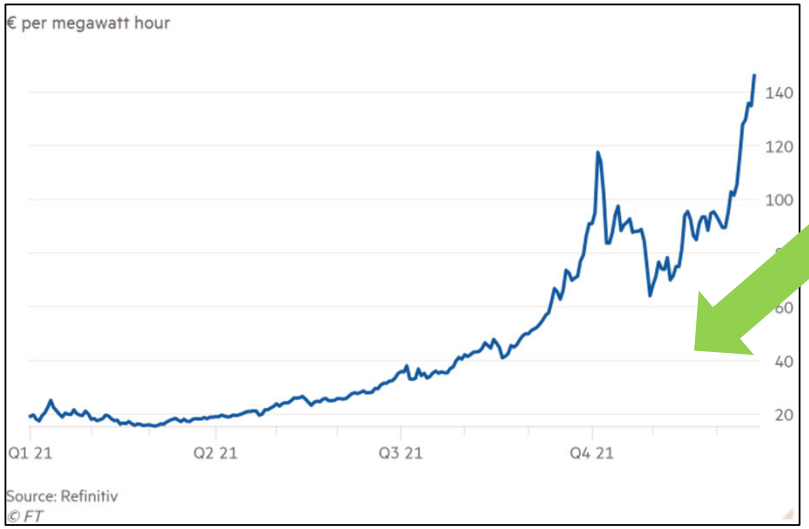
- World leaders in advanced ceramic materials
- Morgan Thermal Ceramics are world leaders in high-temperature thermal ceramics.
- 4 CoE's located globally to develop advanced materials to help meet our sustainability pledge.
- Offer advanced thermal insulation solutions for molten metal transfer applications



Morgan's Sustainability Pledge

Our aspiration	Our 2030 goals
• A CO_2e net zero business by 2050[1] • Use water sustainably across our business • Improve efficiency of our processes at all manufacturing sites to reduce waste	• 50% reduction in Scope 1 and Scope 2 CO_2e emissions • 30% reduction in water use in high and extremely high stress areas[2] • 30% reduction in total water usage[2]

Europe Natural Gas Price



Global Changes

Europe CO_2 Permits

Advanced Molten Metal Transfer Insulation

One area where a reduction in emissions is possible

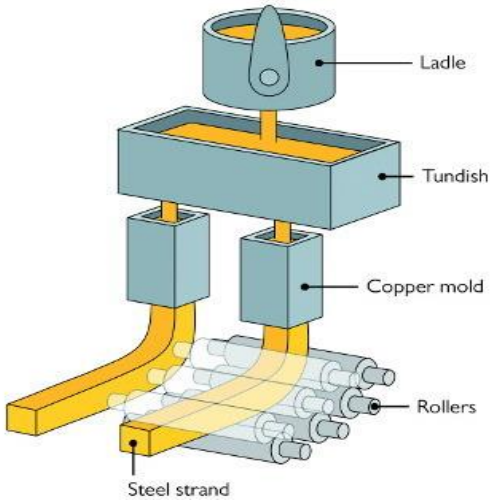
Torpedo Car

Transfer of Metal from Blast Furnace to Induction furnaces OR treatment ladles

Steel or Transfer Ladles

Treatment ladles
Transfer ladles

Tundish



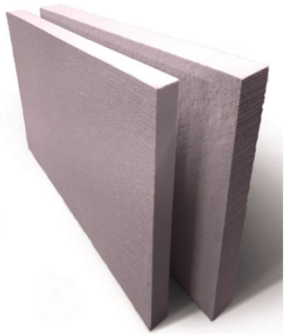
Reservoir that holds metal from ladles and transfers to continuous casting molds

Global changes need advanced Insulation

Our Centre of Excellence in EMEA is committed to developing new solutions for global problems

‘Advanced Ladle Insulation System’

Superwool® 1650SI Board



WDS® LambdaFlex® Super

Heat Flow Calculators
Thermal Modelling

Enhanced safety
Reduction in energy usage
Reduction in CO_2 emissions
Monetary savings

Thermal Ceramics have been successful in launching the 1650SI board in 2020. Since then, we have installed the board (with/without WDS LambdaFlex) in the following applications:

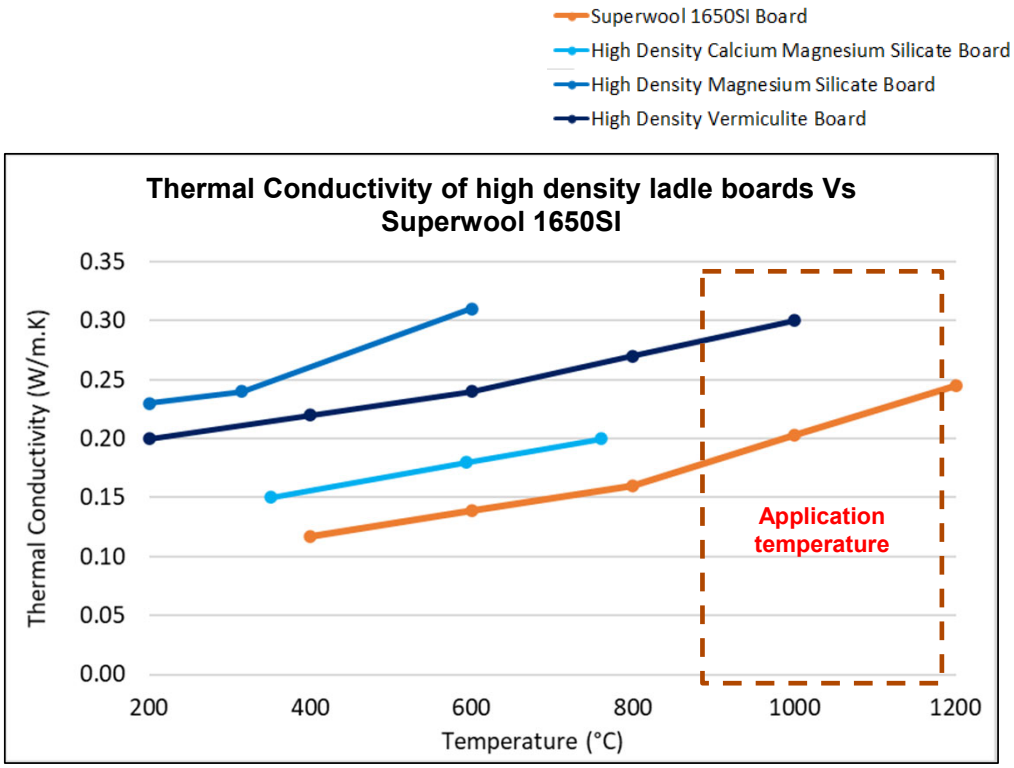
Americas	EMEA	Asia	
305Mt ladle	300MT Ladle	380MT Torpedo Car - China	60Mt EAF - China
180Mt ladle	180Mt Ladle +WDS	120MT Ladle – Taiwan (+WDS)	320Mt Ladle – India (+WDS)
65Mt EAF		60Mt VOD Hood Cover - Taiwan	30Mt Ladle – India (+WDS)
100Mt Ladle		150Mt Steel Ladle - China	120Mt Ladle – Taiwan (+WDS)
120Mt Ladle		120Mt & 150Mt Ladles - China (+WDS)	130Mt Ladle – China

Superwool 1650SI Board

For molten-metal transfer applications

- Structural boards currently used in ladle linings are over-engineered to have very high mechanical strength
- This is aimed to withstand the hoop stresses from the steel pushing on the ladle walls
- But with high density comes poor thermal conductivity

	Low Density Insulating Boards	High Density Structural Boards	Superwool 1650SI Board
Density (kg/m3)	Low 180-310	High ~1250	Medium 820
Strength MPa	Poor ~0.5	Very High ~22	Good 3-4
Thermal Conductivity W/m.K @ 1000C	Excellent 0.2	Poor ~0.3	Excellent 0.2
Comments	Low strength = high compression = poor thermal conductivity	High density = high strength = poor thermal conductivity	Good strength = good compression resistance = excellent long term thermal conductivity



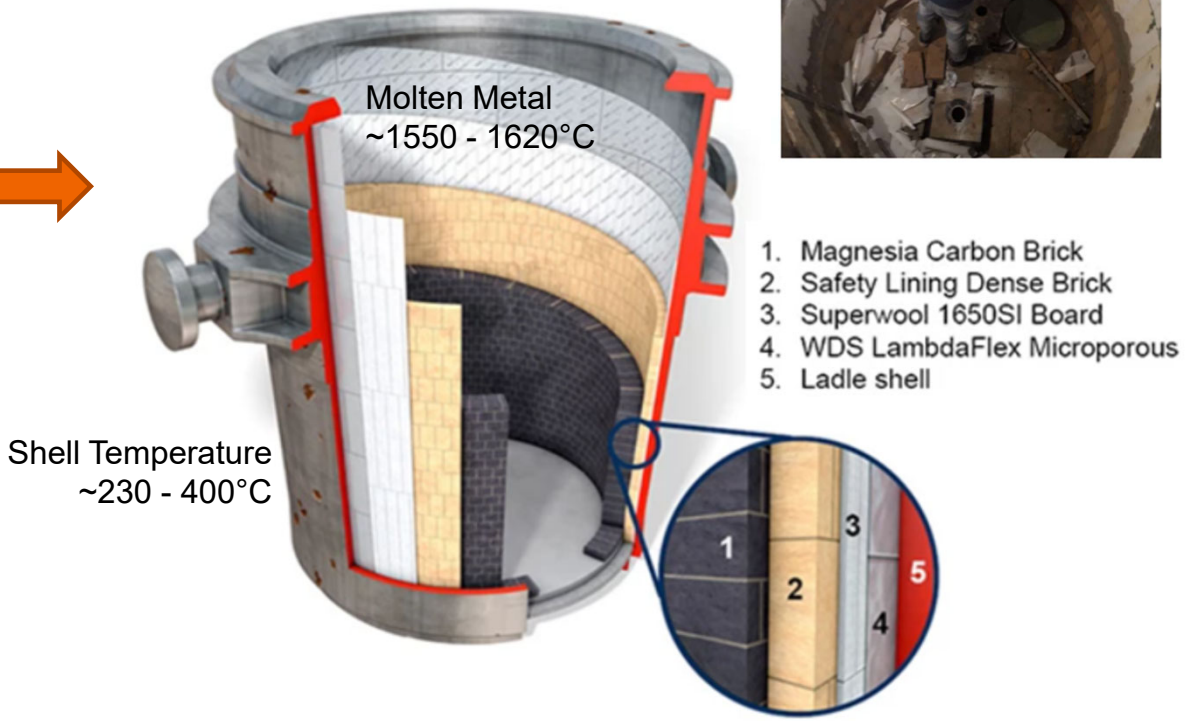
Innovating Ladle Lining

Current Ladle Lining Design

Typical Refractory System in Ladles		
Floor	**Cast or Brick ladle bottom**	
	Cast subfloor	
Barrel	**Working Lining**	**Basic Brick or Castable (Mag Carbon)**
	Backfill	**“Grain” Material (Optional) (High Alumina Castable)**
	Safety Lining	**Castable (High Alumina Bricks)**
	Back-up Lining	**Insulating Board, Paper (Various options)**
	Steel Shell	

Note:
Refractory lining design, thickness and specification of components vary from ladle to ladle depending on various operations and mechanical parameters.

Advanced Ladle Lining Design
‘The Complete Lining Solution’



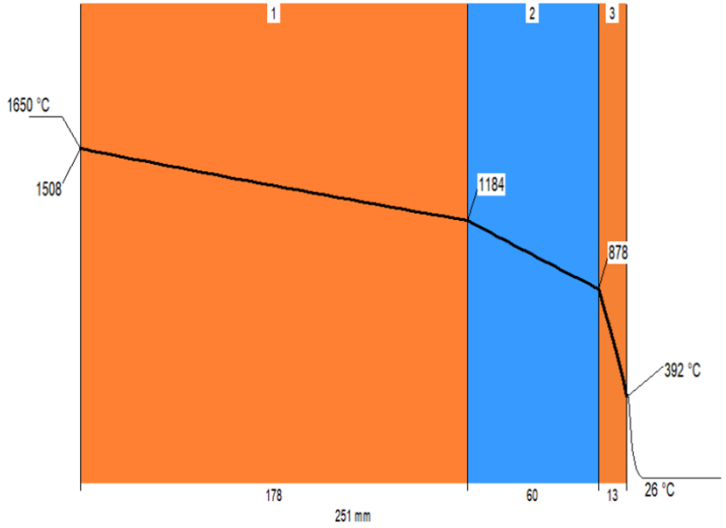
Impact of using an Advanced Insulation

*Changing the board only

	inside	outside		unit	lining characteristics
Ambient temperature	1650	26		°C	111595 W/m (11841 W/m2) Heat loss
Surface temperature	1507.8	392.3		°C	8831 MJ/m heat storage
Heat transition coefficient	100	32.33	(1)	W/m2K	6129 kg/m weight
Diameter	2498	3000		mm	251 mm total thickness

(1) Calculation method ASTM C680, issue 1986 Emissivity=0.90 - wind =0 m/s

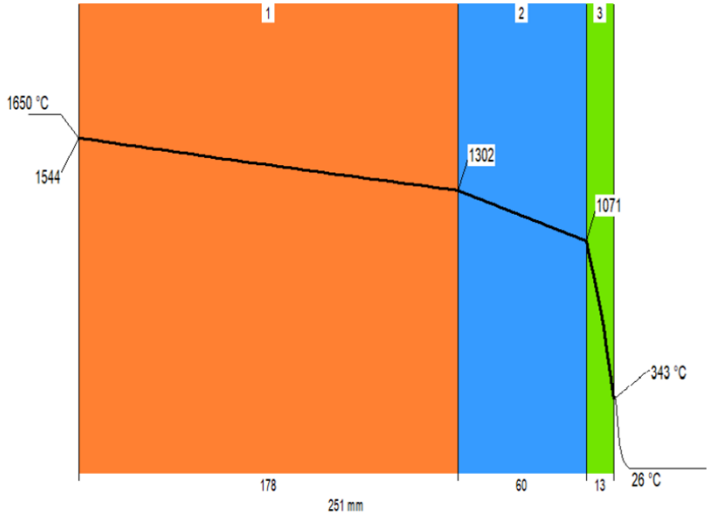
wall layers from inside to outside		Thickn.	Density	Classif.	temperature border	temperature mean	K mean
	Material	mm	kg/m3	°C	°C	°C	W/mK
1	MgO-C brick	178	2970	1750	1507.8	1339	7.31
2	High Alumina brick	60	2800	1620	1184.1	1028	2.384
3	Dense Board	13	1202	1000	877.6	649	0.3221
					392.3		



	inside	outside		unit	lining characteristics
Ambient temperature	1650	26		°C	83260 W/m (8834 W/m2) Heat loss
Surface temperature	1543.9	343.0		°C	9652 MJ/m heat storage
Heat transition coefficient	100	27.87	(1)	W/m2K	6082 kg/m weight
Diameter	2498	3000		mm	251 mm total thickness

(1) Calculation method ASTM C680, issue 1986 Emissivity=0.90 - wind =0 m/s

wall layers from inside to outside		Thickn.	Density	Classif.	temperature border	temperature mean	K mean
	Material	mm	kg/m3	°C	°C	°C	W/mK
1	MgO-C brick	178	2970	1750	1543.9	1418	7.31
2	High Alumina brick	60	2800	1620	1302.4	1185	2.353
3	SW 1650 SI Board	13	820	1350	1076.9	744	0.1616
					343		



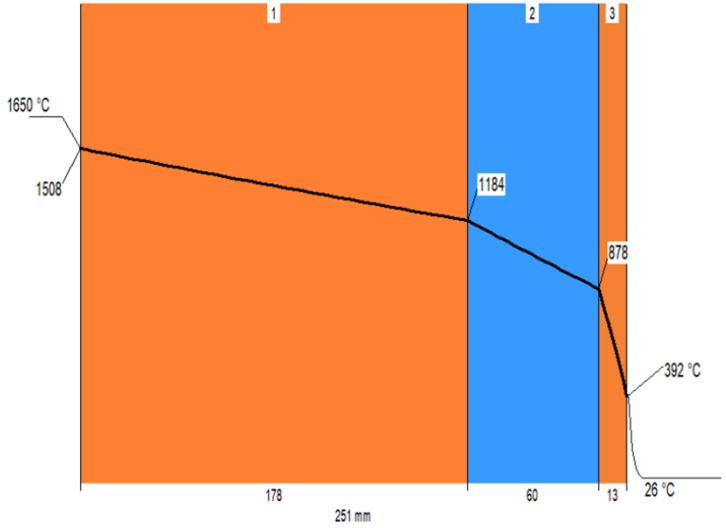
Impact of using an Advanced Insulation

*Changing the board & adding Microporous Insulation

	inside	outside		unit	lining characteristics
Ambient temperature	1650	26		°C	111595 W/m (11841 W/m2) Heat loss
Surface temperature	1507.8	392.3		°C	8831 MJ/m heat storage
Heat transition coefficient	100	32.33	(1)	W/m2K	6129 kg/m weight
Diameter	2498	3000		mm	251 mm total thickness

(1) Calculation method ASTM C680, issue 1986 Emissivity=0.90 - wind =0 m/s

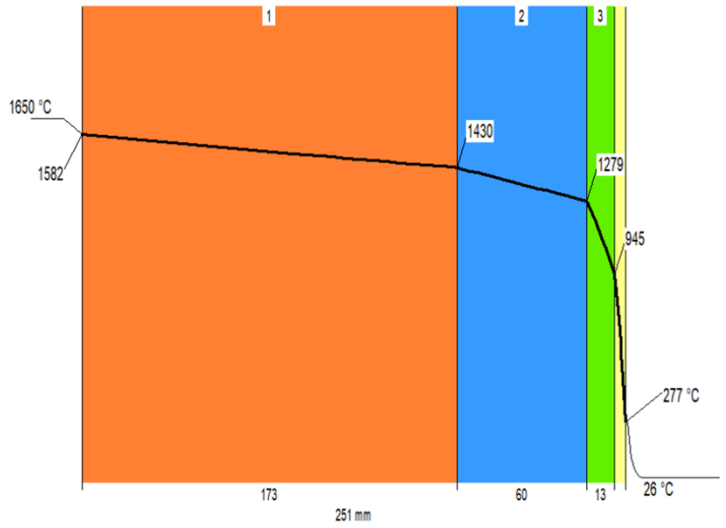
wall layers from inside to outside					temperature		
Material	Thickn.	Density	Classif.	border	mean	K mean
	mm	kg/m3	°C	°C	°C	W/mK
1 MgO-C brick	178	2970	1750	1507.8	1339	7.31
2 High Alumina brick	60	2800	1620	1184.1	1028	2.384
3 Dense Board	13	1202	1000	877.6	649	0.3221
				392.3		



	inside	outside		unit	lining characteristics
Ambient temperature	1650	26		°C	53755 W/m (5704 W/m2) Heat loss
Surface temperature	1581.5	277.4		°C	10391 MJ/m heat storage
Heat transition coefficient	100	22.69	(1)	W/m2K	5961 kg/m weight
Diameter	2498	3000		mm	251 mm total thickness

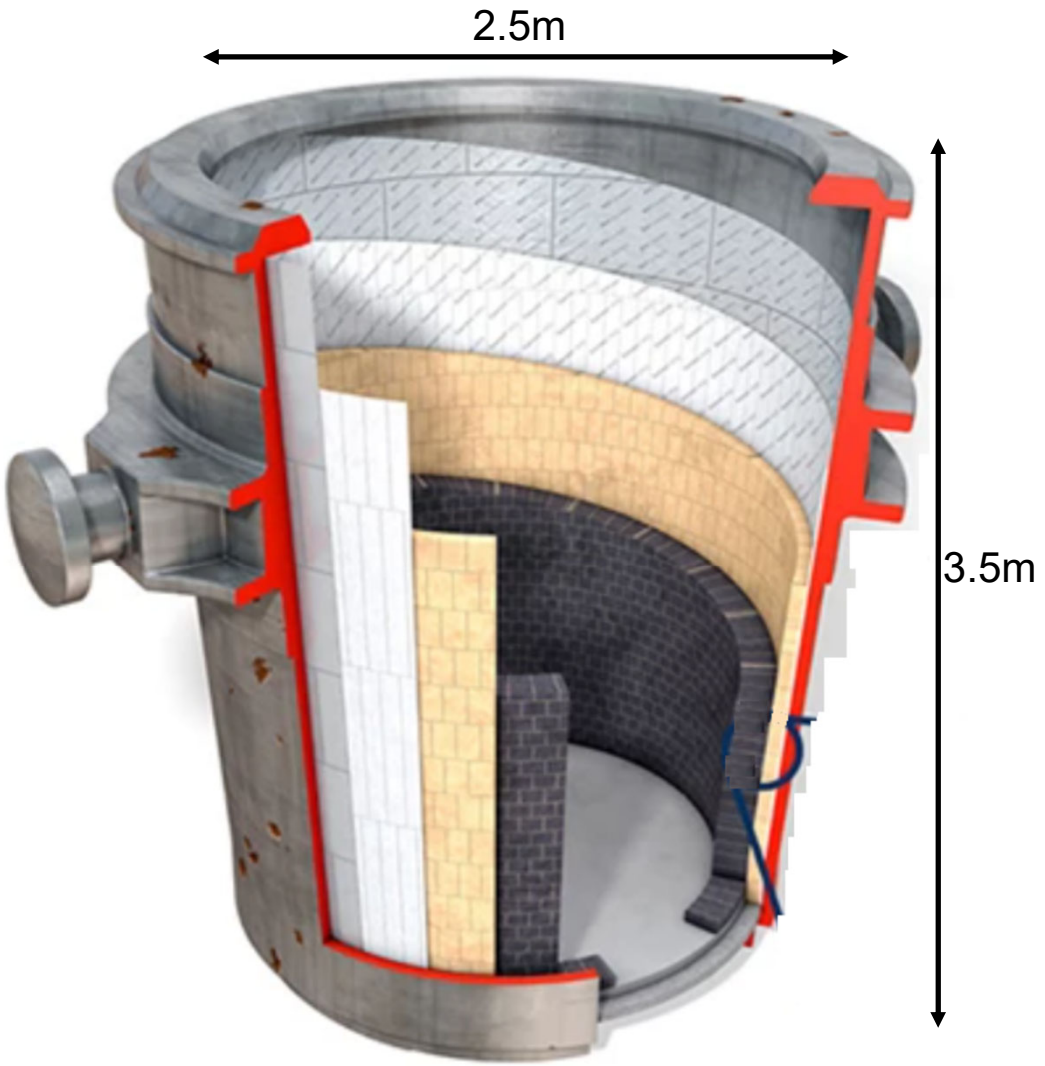
(1) Calculation method ASTM C680, issue 1986 Emissivity=0.90 - wind =0 m/s

wall layers from inside to outside					temperature		
Material	Thickn.	Density	Classif.	border	mean	K mean
	mm	kg/m3	°C	°C	°C	W/mK
1 MgO-C brick	173	2970	1750	1581.5	1502	7.31
2 High Alumina brick	60	2800	1620	1429.7	1353	2.35
3 SW 1650 SI Board	13	820	1350	1279.2	1120	0.2241
4 WDS Lambdaflex Super	5.0	370	1100	945	648	0.0434
				277.4		



Worked example

- Steel transfer ladle
- Internal Surface Area = 27.5m2
- Metal temperature = 1650°C
- Ladle volume = 17m3
- Mass of Steel = 130MT
- 8 hours ‘hot’ per day
- 24 days use per month
- Natural Gas Price = 7.8c / kWh



Impact on Energy / CO_2 / Cost

Ladle Insulation	High-Density Structural Board	Superwool 1650SI	Superwool 1650SI + Lambdaflex
Working & Safety Lining	178mm MgO-C brick CF8L10-EU 60mm high Alumina brick		Working lining -5mm
Insulation Thickness	13mm	13mm	13mm & 5mm
Cold Face Temperature (°C)	392	343	277
Heat Loss (kW/m2)	11.8	8.8	5.7
Total Heat (kW)	326	243	157
Heat loss Per Year (kW·h)	750182	559469	361152
Cost of Energy Lost Per Year Through Lining (0.078 €/kW.h)	€ 58,514	€ 43,639	€ 28,170
Energy Savings	-	€ 14,876	€ 30,344
Additional cost of Insulation (example figures)	-	1000	3000
Payback-Period (Days)	-	21	31

	A	B	C
	PAYBACK CLACULATION WHILE USING SW-1650SI (with/without WDS LAMDAFLEX)		
	Calculation based on Theoritical Heat Loss		
	Fill in the values in cells with orange color		
	Details	**Unit**	**Calculations**
	Ladle Capacity	MT	130
	Ladle Side Surface Area	Square Meter	27.5
	Heat Loss as per Existing lining design	Watt per Square Meter	11841
	Heat Loss as per proposed lining design (SW 1650 SI + WDS Lamdaflex in back-up)	Watt per Square Meter	5704
	Difference	Watt per Square Meter	6137
	Total Heat Difference	Kilo Watt	169
	Total hours of operations a day (when the ladle is filled)	Hrs	8
	Total Heat Saving	KW Hr	1350
	Average no. of day of working in a month	Days	24
	Total Heat Saving per year	KW Hr	388840
	Energy cost per unit	Euro per KWH	0.078
	Total Saving in Euro for a year		30407
	Total investment (additional cost paid) for the new back-up lining	Euro	3000
	Payback-period	No. of Years	**0.10**
		No. of days	**31**

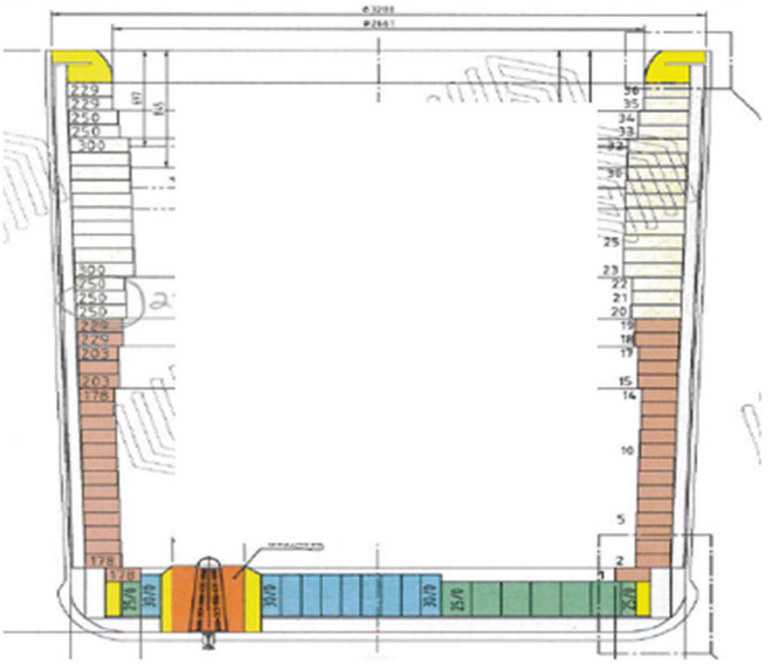
Note: The savings calculator and ROI calculator do not take in to account CO_2 cost – Currently at €84/MT

Microsoft Excel Worksheet

Appendix

Case Study 1
110MT Ladle in Taiwan

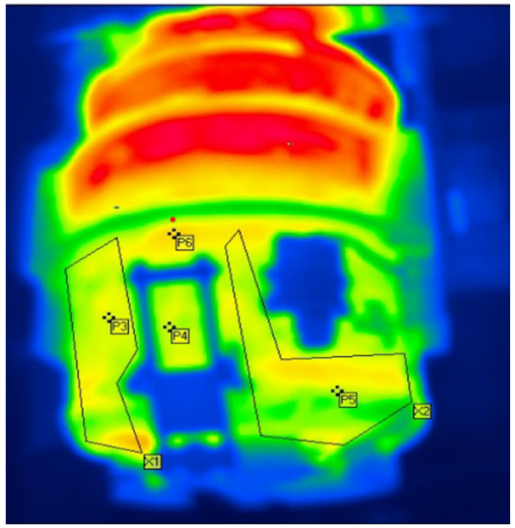
- Customer was using Skamol HS12 Structural Board along with our **WDS LambdaFlex Super** as back-up insulation system
- The ladle shell was noted at 280°C with the new lining and was increasing with use. The ladle relining alarm was set to 450°C.
- The customer chose to replace the Skamol Boards with our **Superwool 1650SI Boards** in this trial, keeping every other lining configuration same.
- 2 ladles - Side by side comparison between 1650SI and Skamol.



- Trial started with two ladles in August 2020; two different plants
- Life expectancy is 1000 cycles
- Metal holding time are approximately:
  - Plant 1 - 70 to 90 minutes
  - Plant 2 - 85 to 120 minutes

Case Study 1
110MT Ladle in Taiwan

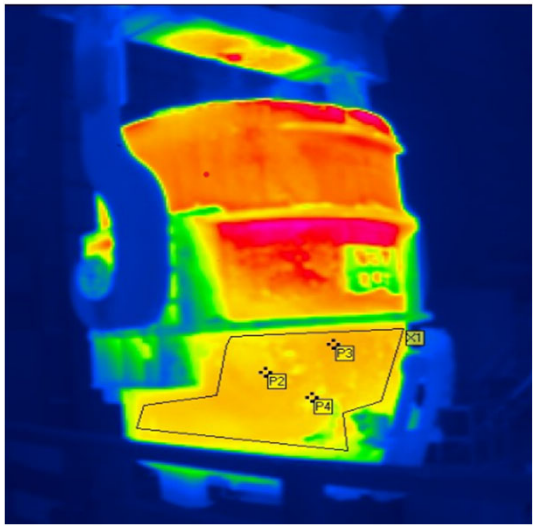
Superwool 1650SI Board



識別碼	平均值	最小值	最大值
X1	258.38	217.88	305.64
X2	253.48	182.78	285.91
P3	261.99		
P4	256.95		
P5	254.85		
P6	288.57		

Average 262°C

Skamol HS12 Board



識別碼	平均值	最小值	最大值
X1	293.18	210.29	312.66
P2	295.35		
P3	308.60		
P4	292.11		

Average 297°C

- Both ladles completed their life expectancy of over 1000 cycles. The customer relined both ladles with 1650SI board because of it superior performance.
- The shell temperature at the liquid steel section was consistent with the heat calculations submitted by Morgan Thermal Ceramics.
- The use of Superwool 1650SI Board resulted in two advantages to the steel makers in terms of operation:
  - The starting temperature of pouring and the subsequent tapping temperatures of the Continuous Casting sequence can be easily managed upon the in-situ operational requirements.
  - The longer sequence of Continuous Casting is achievable and manageable.
- The customer was completely satisfied with the result and has awarded the annual orders amounting to 22 ladles.
- **Superwool 1650SI Boards show superior insulation performance with the lower shell temperature at 30 to 35°C.**
- <u>The payback period of using 1650SI versus the Skamol board was <2 months.</u>

Case Study 2
Torpedo in China

- The customers engineering department started a project aimed at energy saving by relining the torpedo car.
- Taking reference from an overseas case study (case of iron leakage after the renovation of the torpedo in the UK)

Addressing Customer Requirements

1. Good insulation performance to enhance the insulation effect and reduce the temperature by 15-20°C

Key address: ***thin lining with improved insulating performance***.

2. The structural stability of the masonry and the safety of the backing are considered. Increased melt loss in the lining, rapid age reduction and abnormal damage to the backing resulting in iron leakage must be avoided.

Key Address: ***high strength, high classification temperature, good thermal shock resistance.***

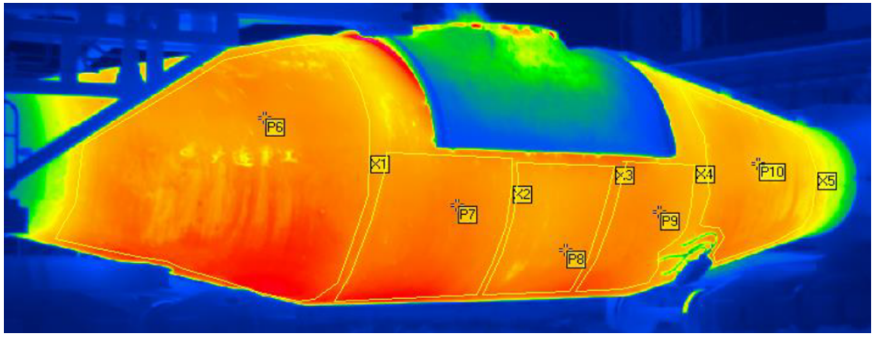
3. Convenience of construction and operation of the equipment, the economic considerations of maintenance and repair.

Case Study 2
Torpedo in China

- The images show the 13mm 1650SI board being installed on the torpedo steel shell.
- 2 x 18mm layers of Magnesium Silicate dense board were installed after this as standard.

Case Study 2
Torpedo in China

单位（℃）	7月	8月	9月	10月	11月	12月	1月	2月	3月	4月	5月	平均
单层高强度纤维板	104.4	106..6	108.1	107.0	111.2	97.3	108.1	98.8	101.1	102.0	104.9	104.4
全部	114.3	114.6	115.3	112.8	112.7	116.1	118.0	127.7	107.2	107.6	113.7	114.5



- During the trial, Morgan Thermal Ceramics carried out thermographic temperature measurements as well as customer assistance in providing feedback on temperature data from steel mill owners.
- The boards were installed for 11 months before the torpedo was removed and the working & safety lining was replaced as standard
- Over the 11 months use, the average temperature drop was 10.1C compared to a similar torpedo without the 1650SI board.
- According to the customers calculations, a 1°C per tonne improvement has resulted in a 0.29 RMB saving.
- Therefore:
  Average temperature drop = 10.1C
  Tonnes = 380Mt
  Saving per use = 3838 RMB
  Saving per use = £465

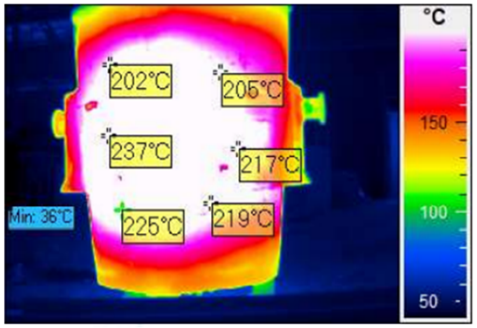
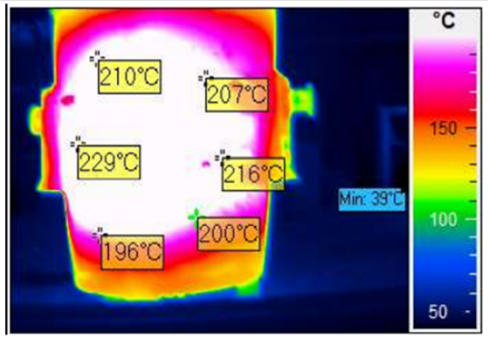
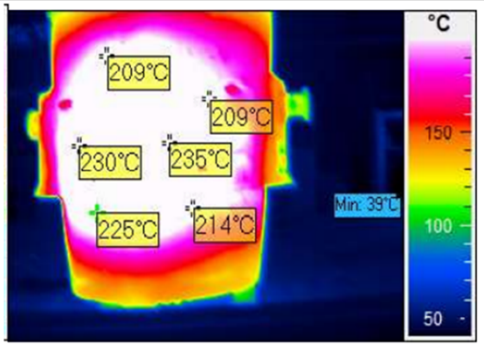
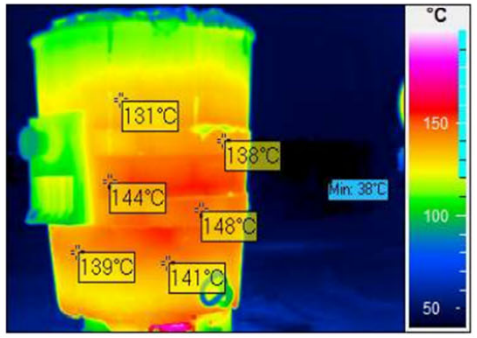
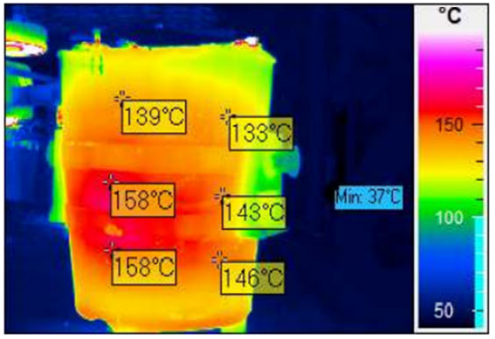
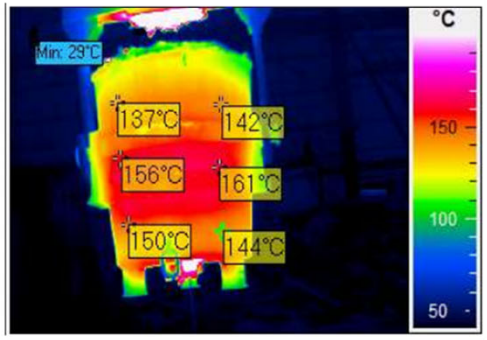
Case Study 2
Torpedo in China

- After the good results from the trial, the customer has ordered sufficient boards to reline 5 x torpedo's and completely remove the magnesium silicate boards from the lining.

- The next 5 torpedo's will be lined with 2 x 18mm layers of 1650SI board – safety lining – working lining.

Case Study 3 - 20MT Ladle in India

- The customer was using a fibre-based structural board in their 20MT transfer ladles
- Morgan Thermal India team approached the customer and provided thermal calculations showing the energy savings of using 1650SI board and Microporous
- The below thermographic images show the ladle with the existing lining and when relined with 1650SI board and WDS LambdaFlex

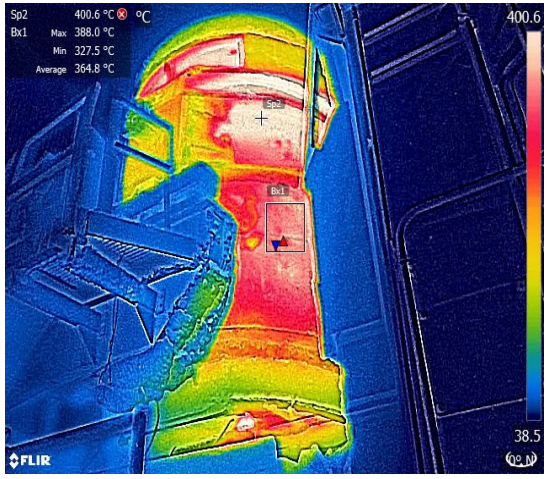
	Before Tapping	After Tapping	After Purging / Before Casting
Existing Lining			
1650SI & WDS LambdaFlex			

Case Study 3
20MT Ladle in India

- As committed by Morgan Thermal India, the cold face temp is around 130-170°C.
- The new lining reduced the cold face temperature by 60-80°C.
- The tapping temperature is around 1590-1615°C; against the earlier practice of 1630-1640°C = 15-20°C reduction.
- This results in energy savings of 100 units per heat = INR 700 per heat ($9.20).
- Considering 300 days and ~9 heats per day, this results in ~1.9 MN INR per year ($25,000 per year) and the payback is less than 3 months.
- The ladle cold face temperature is massively reduced which allowed for longer metal holding time and allowed for flexibility in their operations

Case Study 4
300MT ladle in South Africa

- The customer was using 10mm Silplate 1212S back-up board
- A newly lined ladle of 178mm hot face lining, with reduced safety lining thickness from 50mm to increase capacity.
- The ladle sat in the purging section for double the usual time due to some issues in the plant.
- This meant that the ladle was closer to equilibrium when the thermal scan was taken (around Nov 2020).
- Hot spots of over 400°C were seen near the top with an average temperature of 366°C seen around the middle.
- This shows that the Silplate is not effective in protecting the steel shell and there are risks of burn through.
- Thermal calculations performed by Morgan Thermal Ceramics provided similar cold face temperatures.



Case Study 4
300MT ladle in South Africa

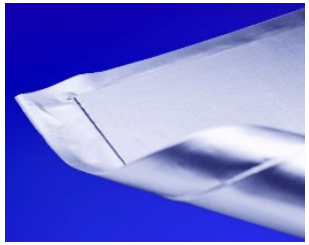
Current Lining

Newly Lined Ladle:

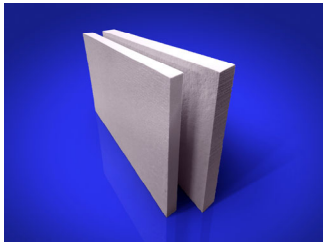
wall layers from inside to outside		Thickn.	Density	Classif.	temperature border	temperature mean
	Material	mm	kg/m3	°C	°C	°C
1	Magnesia-Carbon Firebrick 10C	178	3050	1750	1648.6	1400
2	60 Alumina Firebrick 1	25	2550	1630	1177	1082
3	Silplate 1212S	10	850	1200	987.8	709
				Ladle Temperature:	381.8	

Worn Ladle Requiring Reline:

wall layers from inside to outside		Thickn.	Density	Classif.	temperature border	temperature mean
	Material	mm	kg/m3	°C	°C	°C
1	Magnesia-Carbon Firebrick 10C	30	3050	1750	1648.1	1588
2	60 Alumina Firebrick 1	25	2550	1630	1529.1	1382
3	Silplate 1212S	10	850	1200	1237.3	905
				Ladle Temperature:	464.6	



Proposed Lining



Newly Lined Ladle:

wall layers from inside to outside		Thickn.	Density	Classif.	temperature border	temperature mean
	Material	mm	kg/m3	°C	°C	°C
1	Magnesia-Carbon Firebrick 10C	178	3050	1750	1648.9	1526
2	60 Alumina Firebrick	25	2550	1630	1413.6	1347
3	Superwool 1650SI	10	850	1650	1279.9	1120
4	WDS Lambdaflex Super	3.0	360	1100	932.4	673
				Ladle Temperature:	342.9	

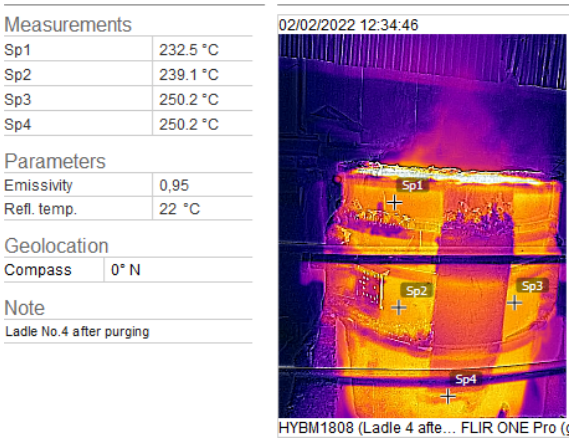
Worn Ladle Requiring Reline:

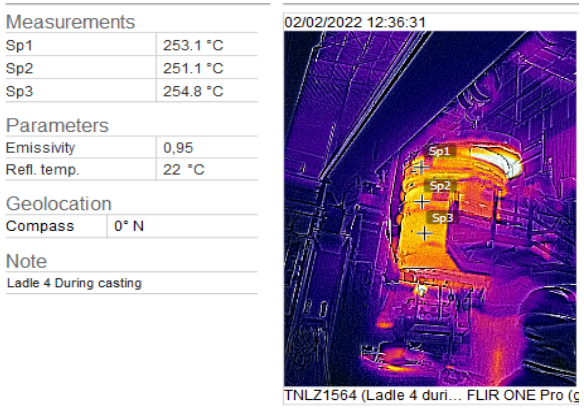
wall layers from inside to outside		Thickn.	Density	Classif.	temperature border	temperature mean
	Material	mm	kg/m3	°C	°C	°C
1	Magnesia-Carbon Firebrick 10C	30	3050	1750	1648.7	1624
2	60 Alumina Firebrick	25	2550	1630	1600.5	1516
3	Superwool 1650SI	10	850	1650	1432.2	1261
4	WDS Lambdaflex Super	3.0	360	1100	1063	770
				Ladle Temperature:	385.2	

- Using 1650SI and 3mm microporous, the cold face of the new lining was reduced by ~40°C
- After an 80% erosion of the working lining, the cold face using the Silpate 1212S was 465°C
- After an 80% erosion of the working lining, the cold face using the 1650SI & LambdaFlex was 385°C

Case Study 4
300MT ladle in South Africa

- Morgan Thermal Ceramics performed further calculations and showed the benefits of using 1650SI with and without WDS LambdaFlex microporous
- The customer was conscious about price, but after seeing the improvements gained from microporous in the thermal calculations, they decided to include microporous in the trial





	Number of heats	Average shell temperature
Ladle with Silplate 1212S	46	286
Ladle with 1650SI & WDS LambdaFlex	39	245

- The last thermographic images were taken in December, these showed the 1650SI board and 3mm microporous provided a ~40°C reduction in cold face temperature = 14% drop.
- The customer was very pleased with the result and the fact our thermal calculations were proven by the real-world trial.