PRESENTATION ON QUALITY IMPROVEMENT BY ELECTRO SLAG RE-MELTING (ESR)

FROM

SUNFLAG IRON AND STEEL CO. LTD

INTRODUCTION

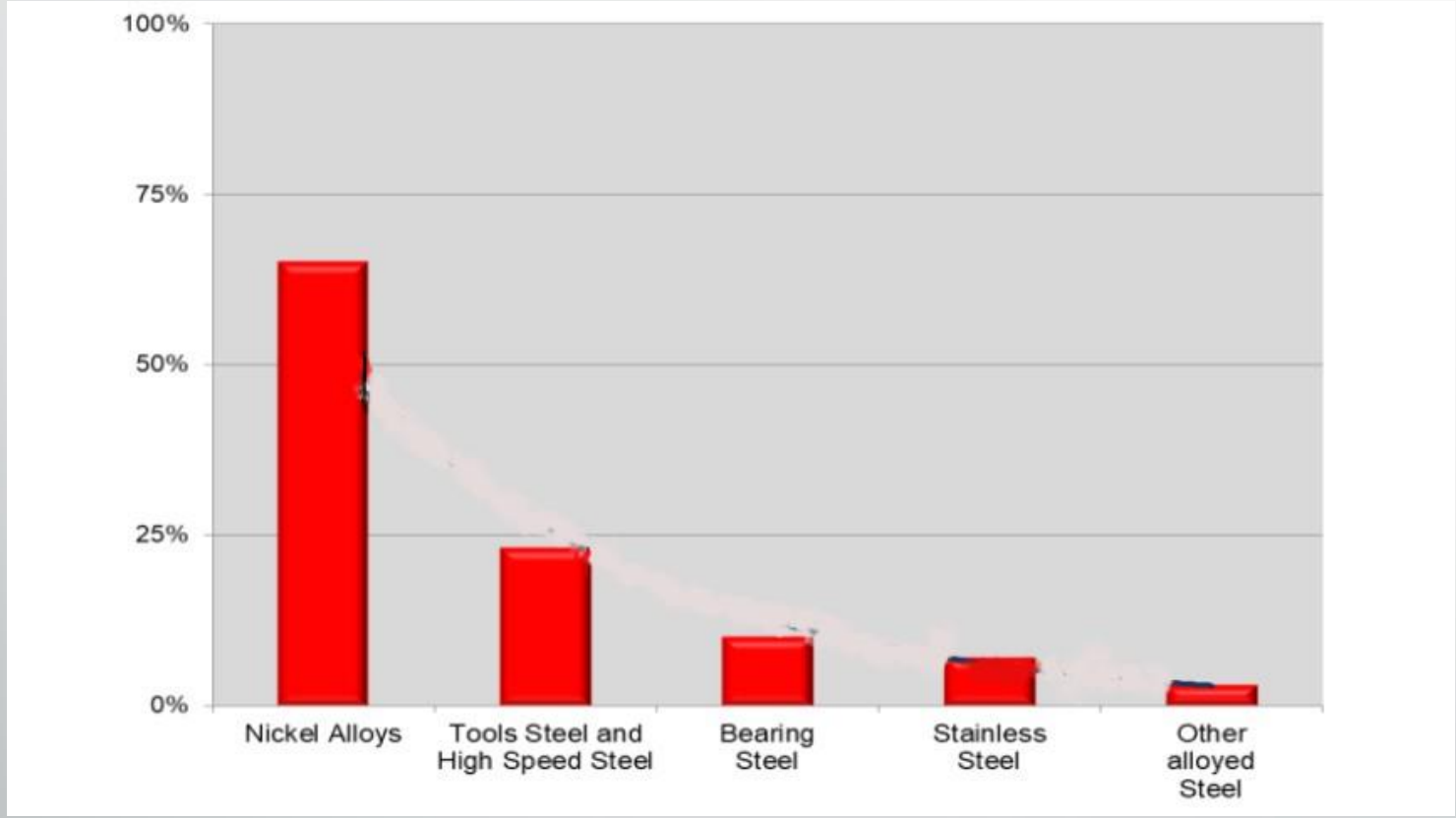
ESR Re-melting is in use since 1960, first in manufacturing of Ni-Base alloys & now increasingly, in production of high-grade steel as well.

In 2016,worldwide high alloy steel production was roughly 154 million tones . In total, roughly 5 Million tons of steels are ESR re-melted grade.

Nickel Alloys	**390,000 tons**
Tools Steel and High Speed Steel	**2,340,000 tons**
Bearing Steel	**6,400,000 tons**
Stainless Steel	**38,740,000 tons**
Other alloyed Steel	**106,130,000 tons**

Annual production for 2016 of high alloyed steel

Re-melted product market share in 2016



Nickel Alloy- 3 Million T

Tool Steel & HSS- 1 Million T

Bearing Steel – 0.6 Million T

Stainless Steel- 0.3 Million T

Other Alloys – 0.1 Million T

Use of ESR Alloys in Advanced Technology Applications

Aerospace

Discs, Rings and Blades in engines
Studs, Bolts, Rivets
Structural Parts,
Bearings and Landing Gear

Medical

Stents
Pacemaker wires
Dental Wire

Oil & Gas

Tools
Safety valves, Pipe joints
Fittings / Flanges / Seals

Power Generation

Blades for gas turbines
Discs, Rings, Shafts
Bearings
Nuclear applications

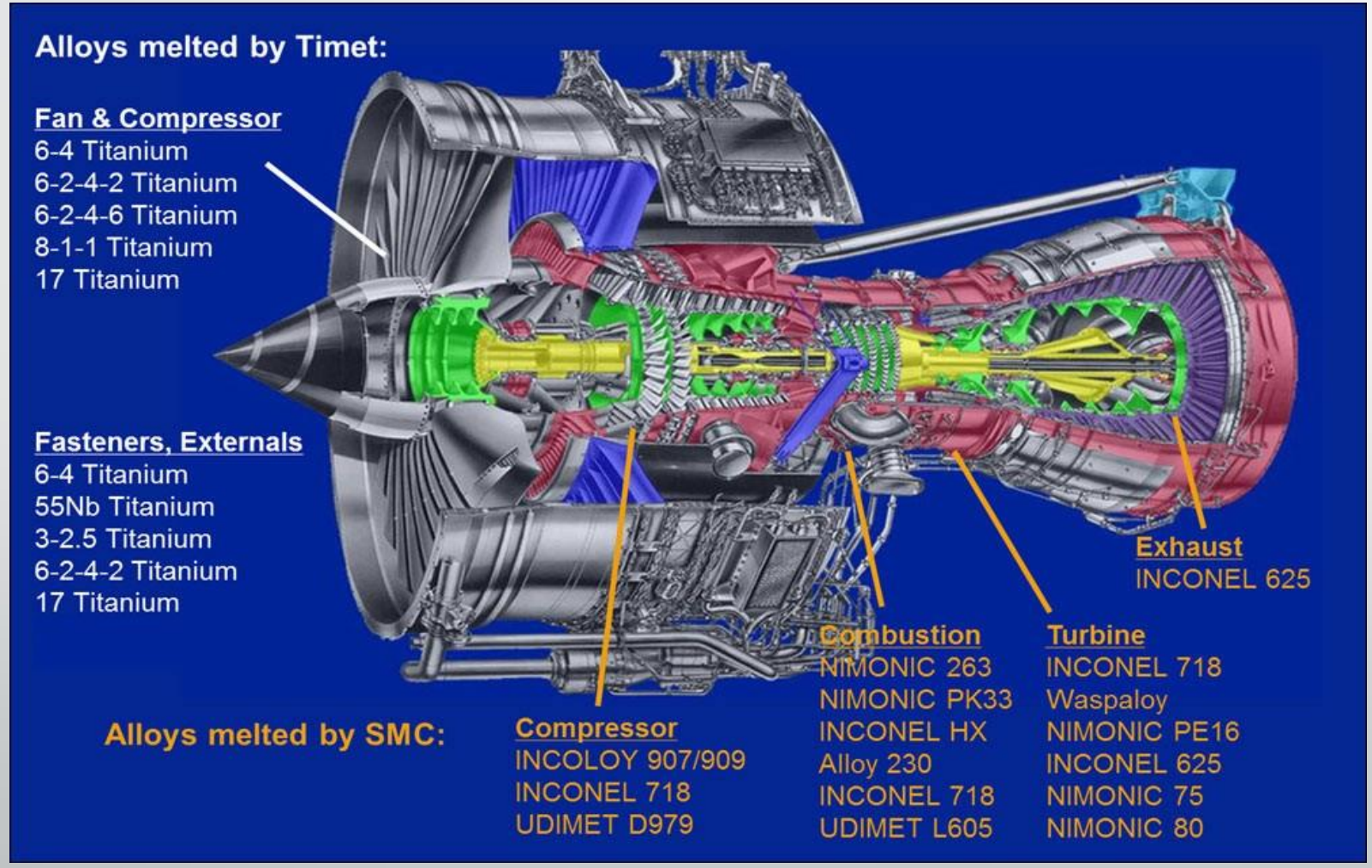
Tools

Extrusion Tools
Die Casting Moulds
Precision Moulds
Coining Tools
Forging Tools

Transport

Injection Parts
Special valves
Piston Rings
Turbo Charger
Bearings

AIRCRAFT ENGINE



Necessity of Advanced Technology Process For Hi-Tech Products

- IN NATURE MATERIALS ARE RARELY PURE.

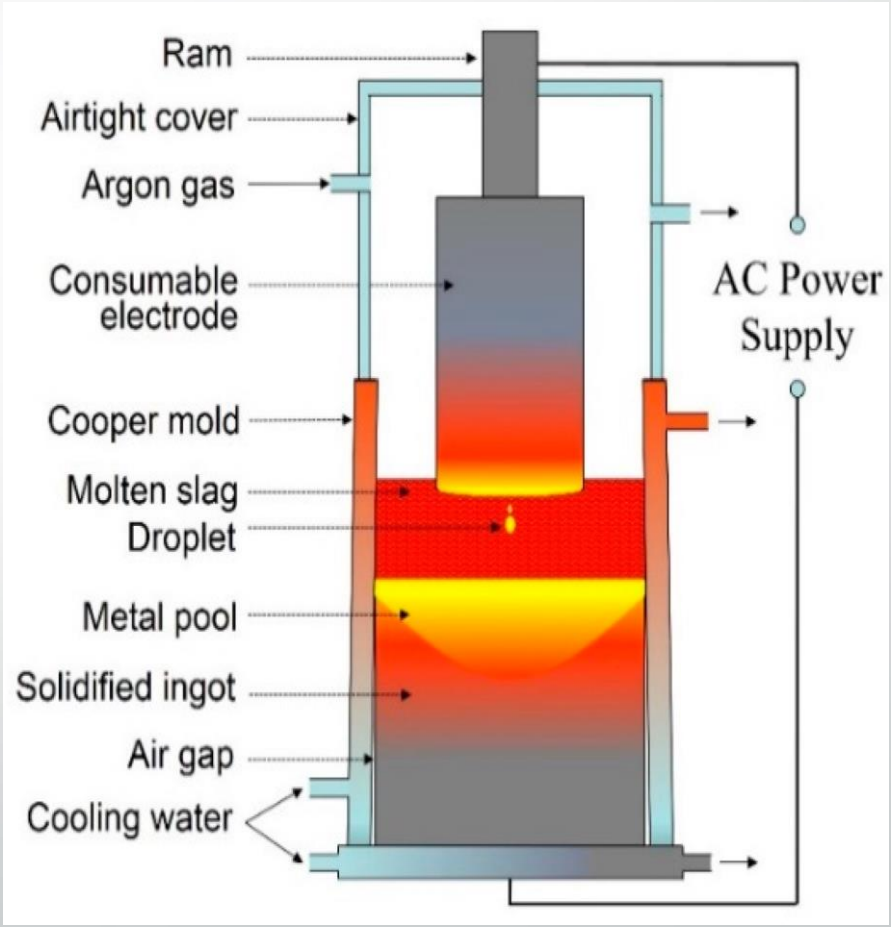
- SUCH MATERIALS HAVE THE FOLLOWING IMPURITIES
  - INCLUSIONS LIKE OXIDES, ALUMINA, SULPHIDES, SILICATES AND NITRIDES i.e. NONMETALLIC IMPURITIES.
  - GASES LIKE OXYGEN, HYDROGEN AND NITROGEN.
  - TRACE ELEMENTS LIKE LEAD, BISMUTH, SULPHUR, PHOSPHEROUS, GOLD, TIN, ETC [METALLIC IMPURITIES]…

THE ABOVE IMPURITIES CANNOT BE REMOVED OR REDUCED TO THE LEVEL REQUIRED FOR HI TECH INDUSTRY APPLICATION BY CONVENTIONAL TECHNOLOGIES LIKE [EAF / LRF / VD / AOD ETC..]

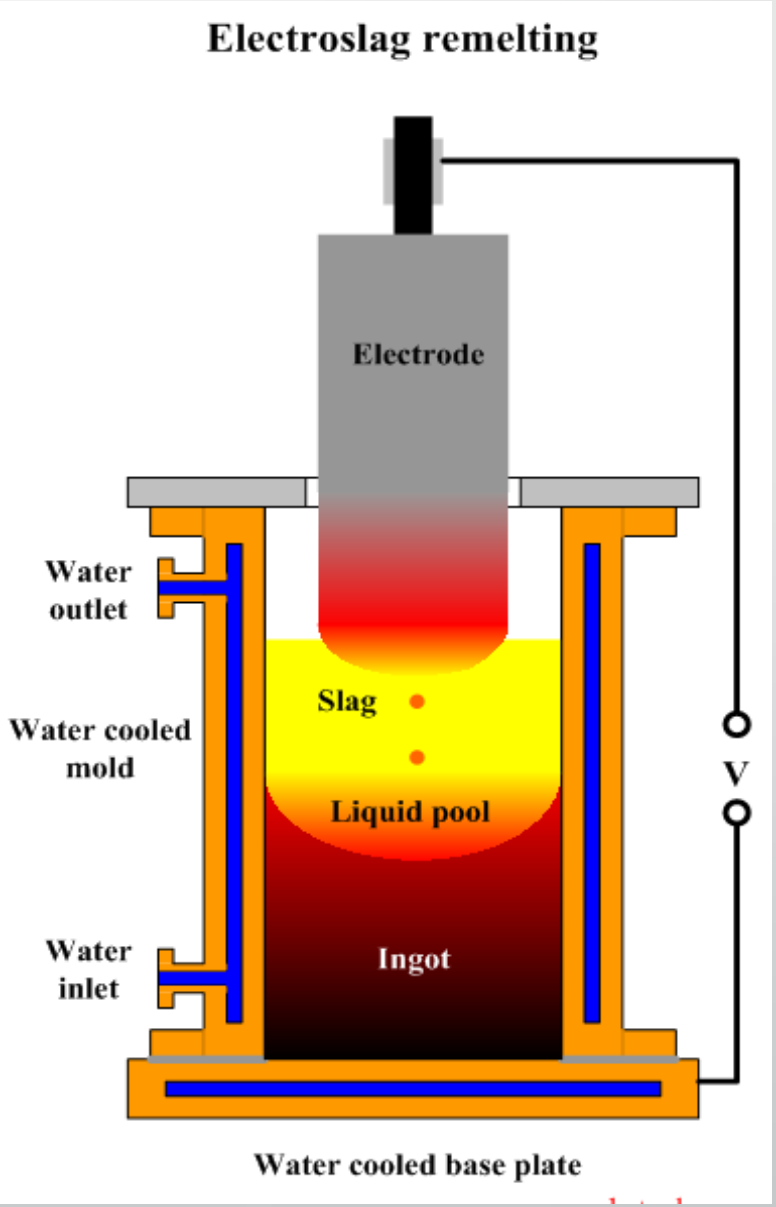
- HENCE **MORE ADVANCED TECHNOLOGIES** OF MELTING, AS BELOW, WERE DEVELOPED AND USED IN THE RECENT DECADE :
  - VACUUM INDUCTION MELTING [VIM]
  - VACUUM ARC REMELTING [VAR]
  - ELECTRO SLAG REMELTING [ESR]

ESR PROCESS

- ESR Re-melts and Refine the material, which is already cast as ingot by conventional EAF, AOD VD, LRF and VIM etc. which is named as electrode in ESR
- In other words the material which is originally produced by conventional steel making process and cast as ingot is again re-melted at ESR.



- At start of process current flows from the electrode through slag to the starting plate kept at the bottom of the water-cooled mould. The slag will be super-heated and liquid metal drops from the electrode & pass through slag to the base plate. Then it builds up slowly up as new and refined ingot.
- To avoid any oxidation & hydrogen pickups runs under protective atmosphere.
- While the electrode at the top is gradually being consumed, there refined material grows upwards from the bottom of water-cooled mould.
- The achievement of constant and continuous melting rate & material flow is essential for entire process
- The typical ESR slag is based on CaF_2,CaO & Al_2O_3.



ASPECTS OF ESR

ASPECTS	PRODUCT STRENGTH OF 1000mm ESR
➢ Energy Consumption (KWH/T)	1100
➢ Melt Rate (Kg/Min)	13.5
➢ Re-melting effect in gas contact	No Change
➢ Re-melting effect in alloying element	No modification & maximum homogeneity
➢ Surface Preparation on ESR ingot	Normally no preparation (not ground or peeled)
➢ Sulphur content	Slag reaction resulting Sulphur reduction
➢ Carbide distribution	Good distribution due to less dendritic arm spacing.
➢ Smooth Surface	Due to slag skin formed on the surface

Process characteristics of Melting and Re-melting of Hi-Tech Alloys

*open ESR- **inert gas ESR

Steel work processes characteristics	EAF	Secondary Metallurgy		VIDP	Special melt process		
		LF	VD		ESR*	IESR**	VAR
Lowest content							
Phosphor							
Sulphur							
Oxygen							
Carbon							
Hydrogen							
Nitrogen							
High level on cleanliness(Super clean)							
Extremely low macro- micro segregations (structure)							
High cleanliness in spite of very low Al and Si-contents							
Controlled Ti and Al distribution in the ingot							
Melt Temperature control							

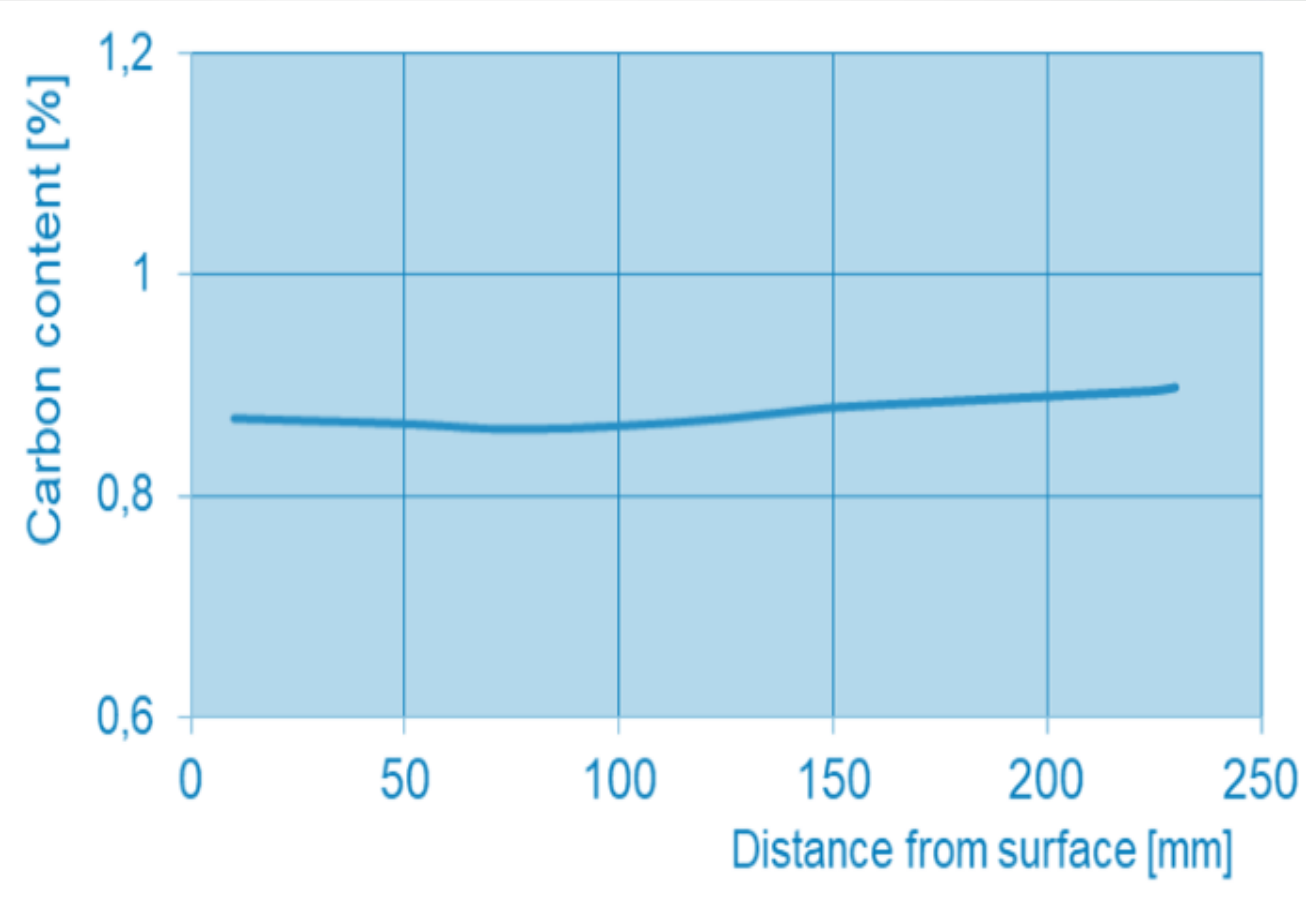
Conventional

Re-melted

- Not achievable
- Excellent
- Good
- Achievable (Precautionary Measure)

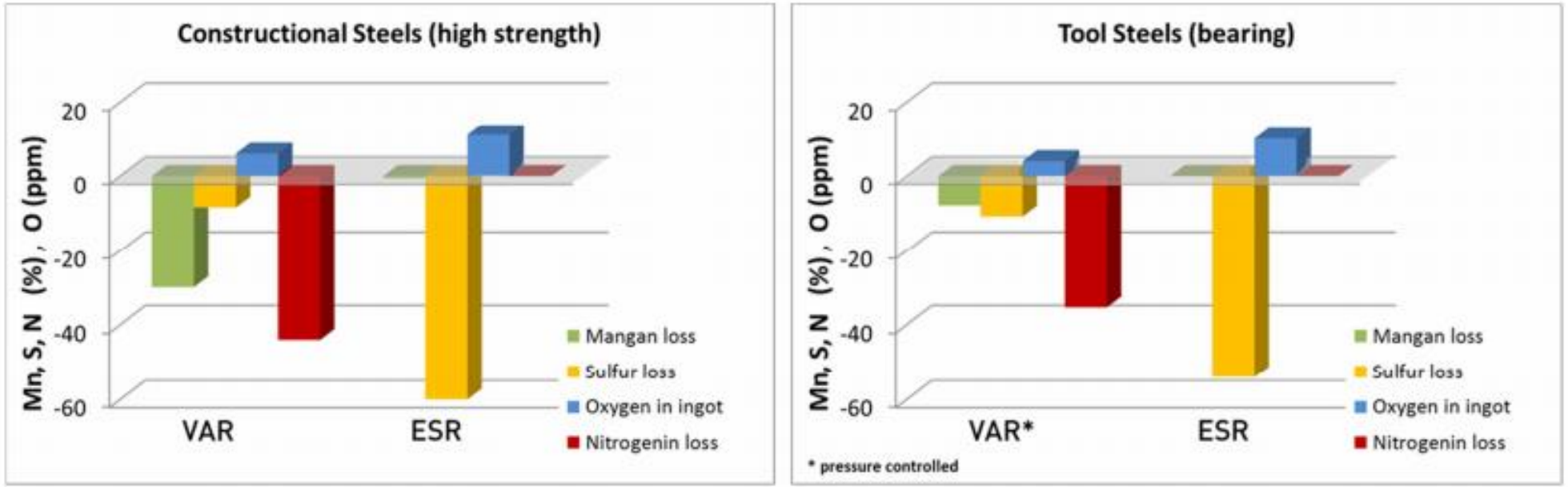
Carbon distribution over the ingot cross section in ESR ingot

Due to the improvement of carbon distribution in the refined ESR ingots it doesn't contain white spots which are mainly metal carbides



Carbon distribution over the ingot cross section with 460mm diameter on High Speed Steel

Changes in ESR Re-melting

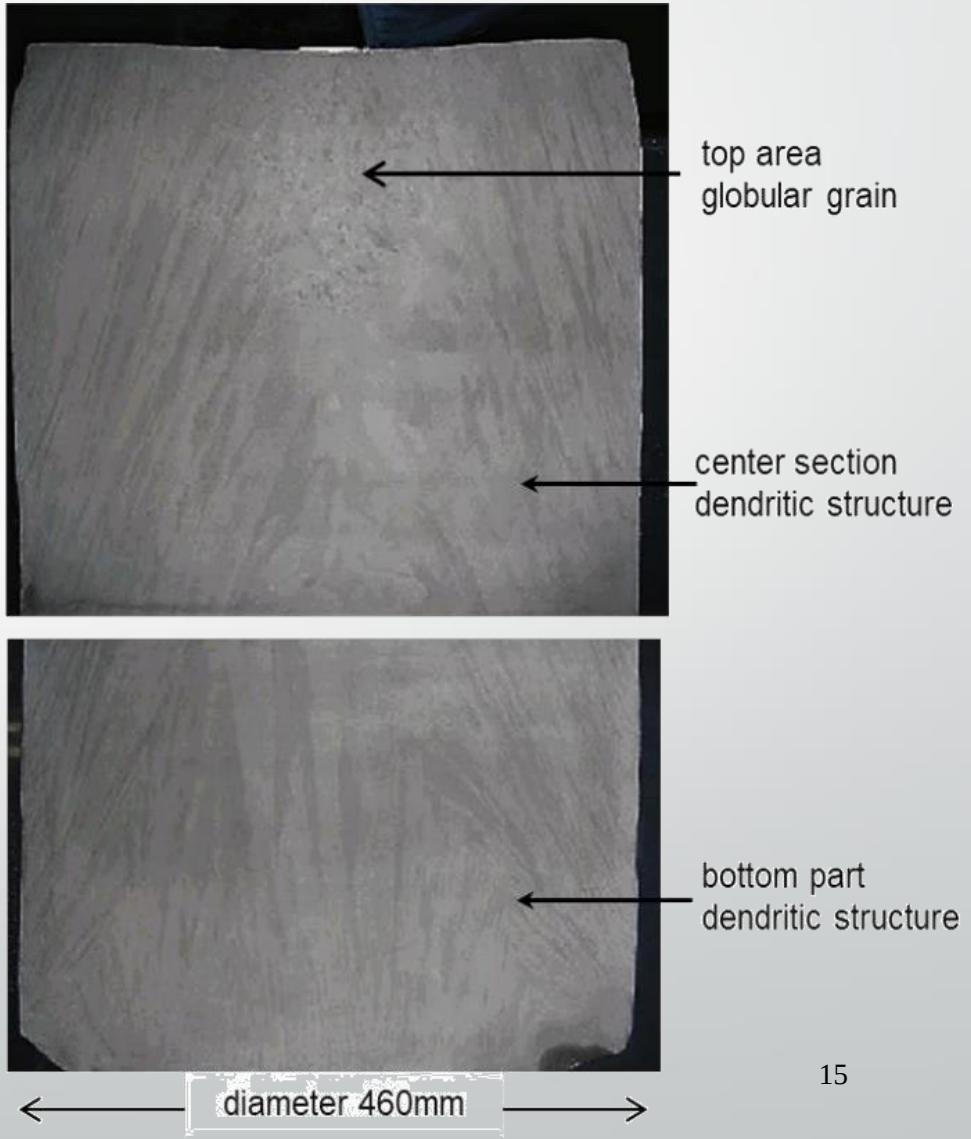


Changes in level of Oxygen and Sulphur in ESR Depicted in above figure

Structure of an Electro Slag Re-melted ingot

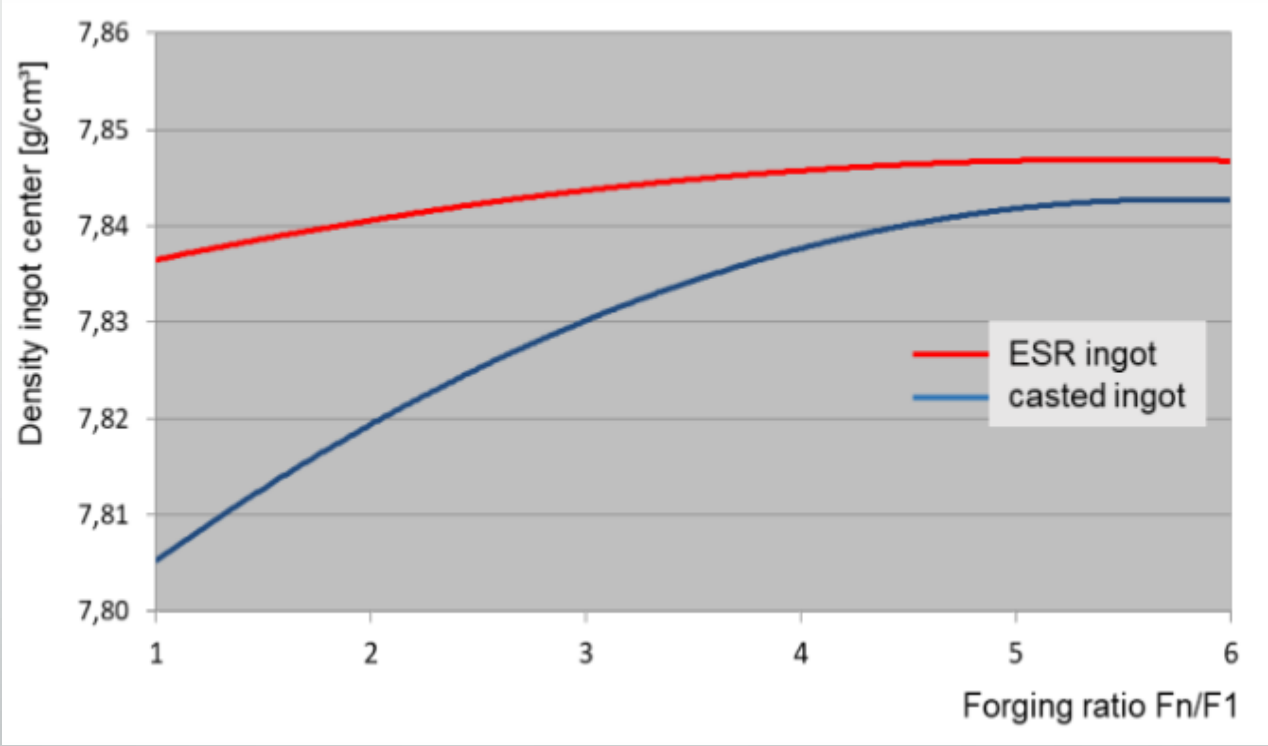
Via the smaller and controllable liquid metal pool resulting directional solidification of the ingot

This is beneficial for macro & micro structure of re-melted ingots. The figure shows the macro structure of ESR ingot with a clear dendritic structure, globular grain at the top with reduced shrinkage with no voids at the top.



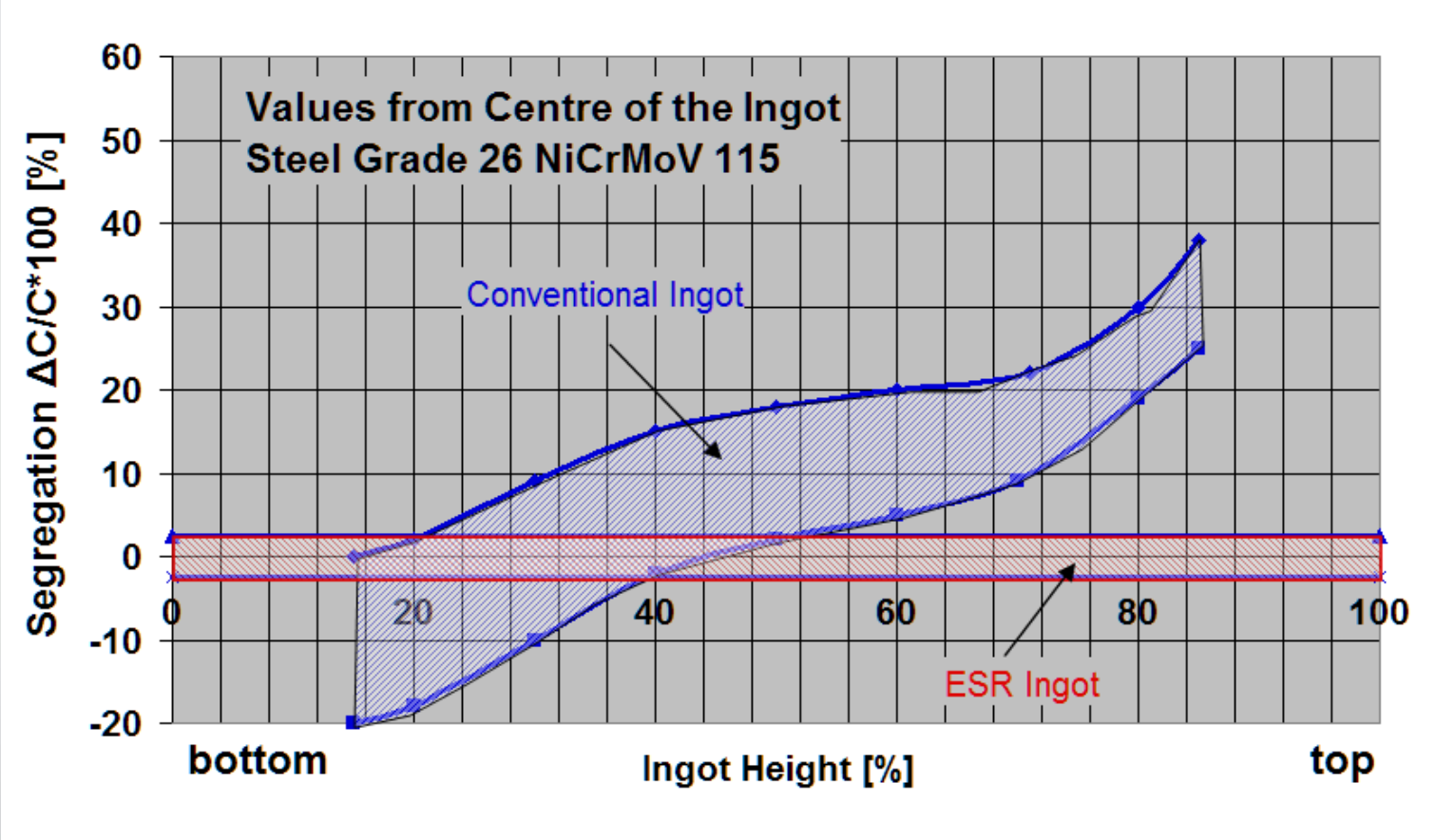
Density of ESR ingot

Due to smaller dendritic arm spacing as compared to conventional cast ingot. The figure shows clearly with lower forging ratios higher ingot density can be achieved as compared to conventional ingot. This effect can be used significantly to reduce the amount of deformation needed in forging/rolling.



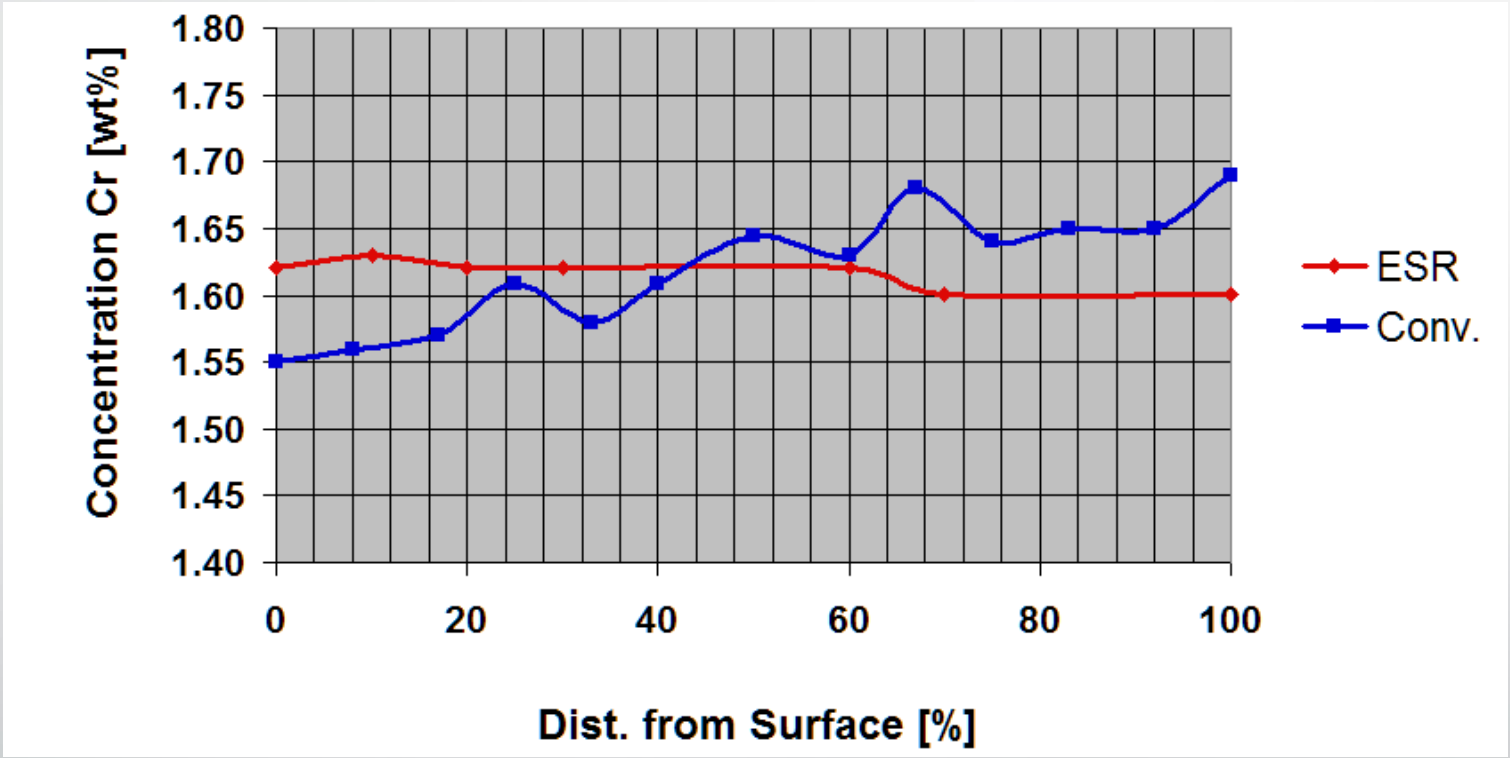
Increased density by electro slag re-melting

Segregation of Carbon



Carbon segregation before (blue colour) and after ESR (red colour) processing measured over the ingot height

Concentration of Alloying elements over the cross section of Steel

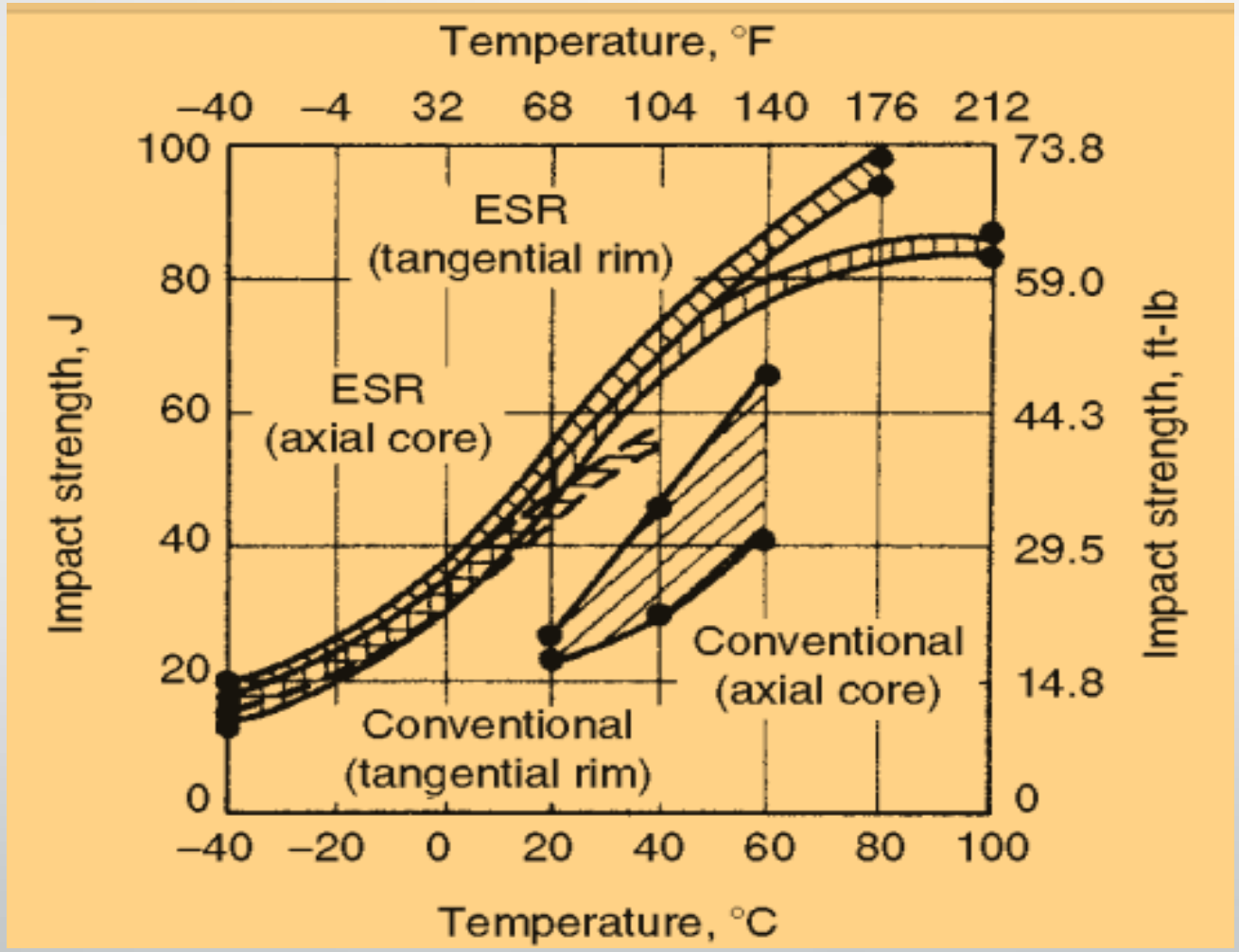


Chromium segregation before (blue colour) and after ESR (red colour) processing measured over the ingot cross section in Grade 26NiCrMoV115

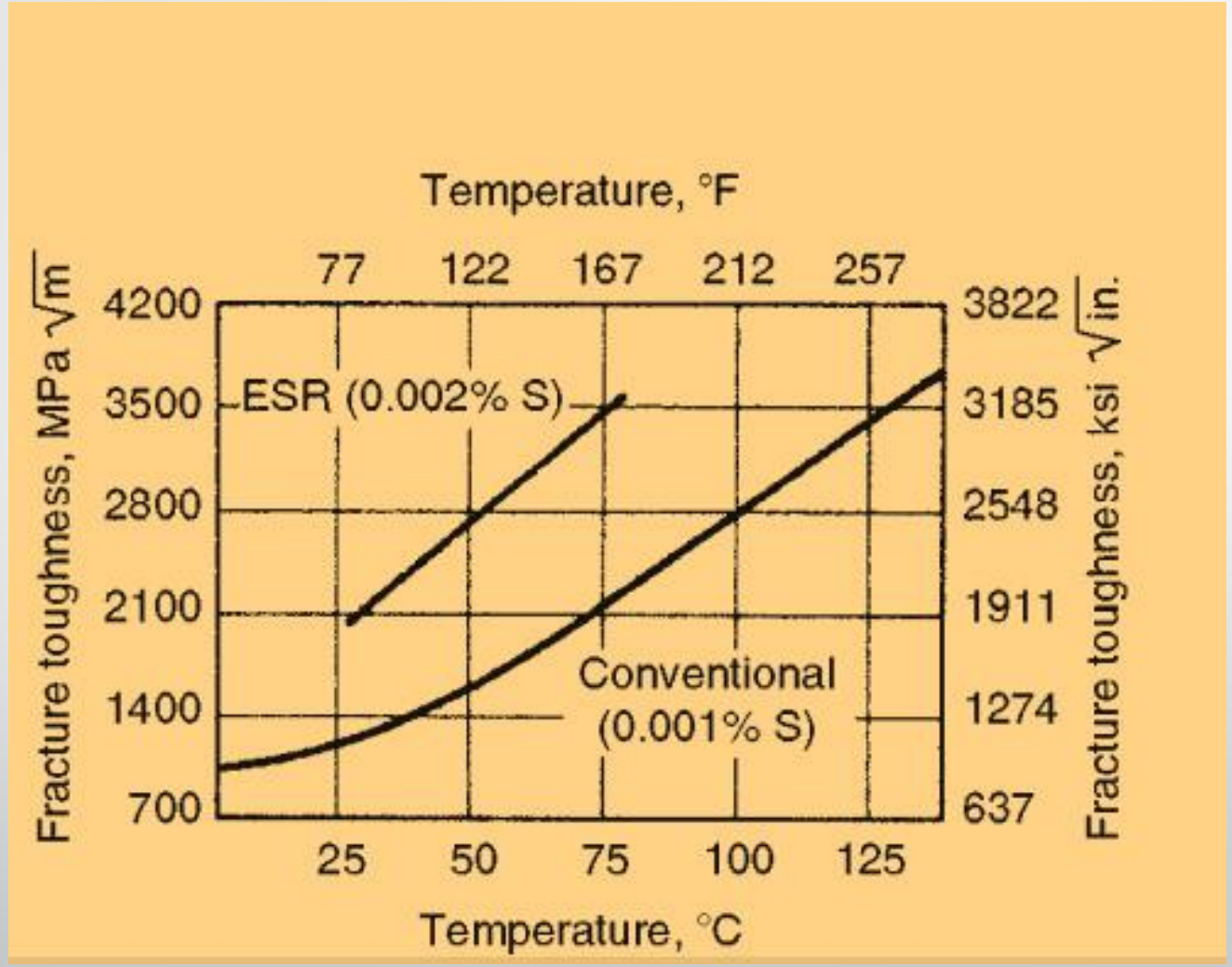
MECHANICAL PROPERTIES COMPARISON OF DIFFERENT TECHNOLOGIES ON GRADE 4130

	Air-melt	ESR
Ultimate Tensile Strength psi	180,000	189,500
0.2% Offset Yield Strength psi	160,000	173,000
Percent Elongation	10	15.7
Percent Reduction in Area	22	47.4
Impact Strength ft-lbs (at -40°F)	11.5	19.2

IMPROVEMENT OF IMPACT STRENGTH IN ESR PRODUCTS



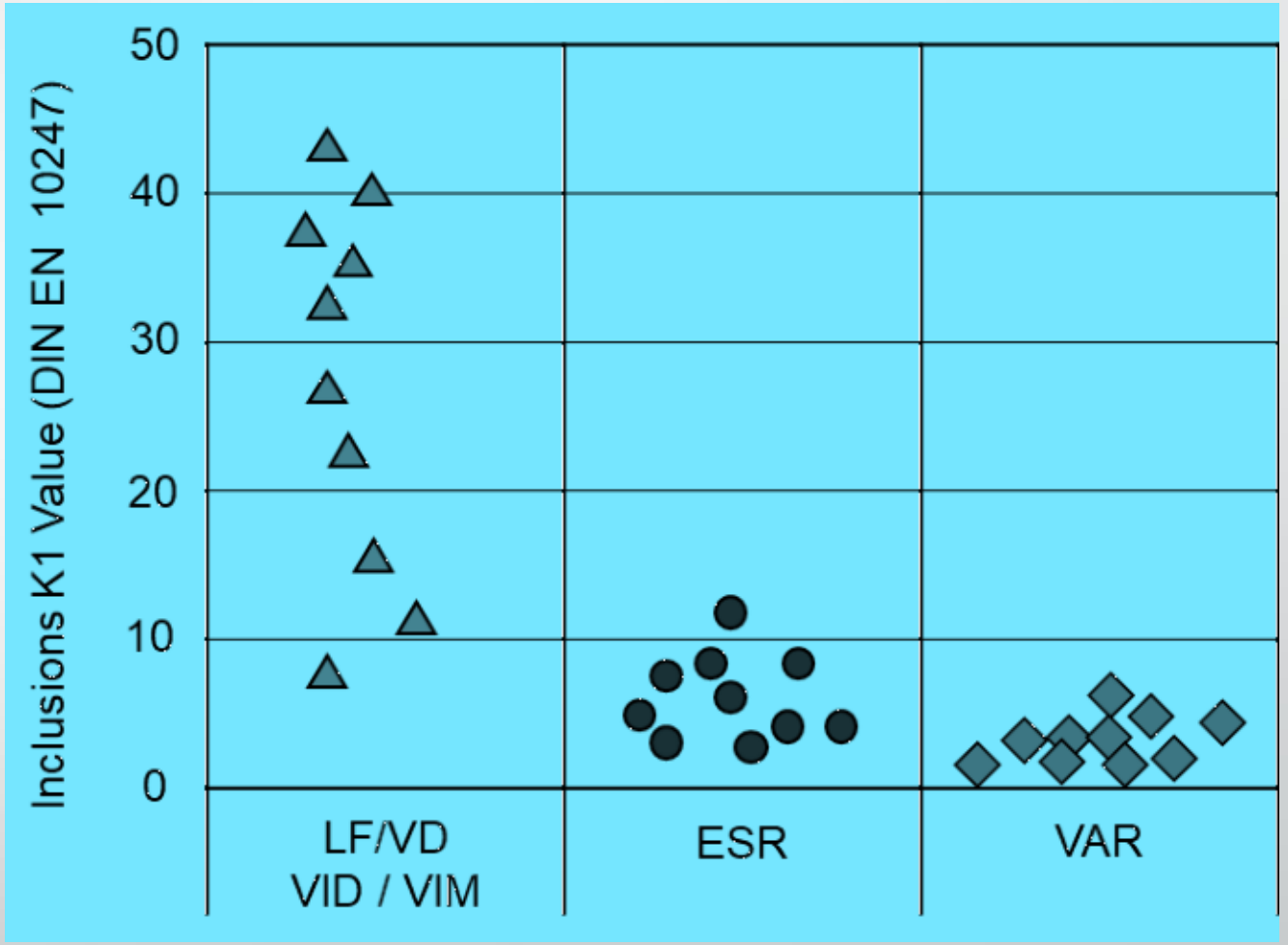
IMPROVEMENT OF FRACTURE TOUGHNESS IN ESR PRODUCTS



Cleanliness of ESR ingot

The homogenization of alloy material is another benefit of this re-melting technology.

The cleanness value describes the number of non-metallic inclusions in a given material, when K,value is lower inclusions are also lower , which is desired.



Cleanliness values of different melt processes measured on a 17-4 PH

Economic View.

- Re-melting process cost additional investment, consumption of energy, needs additional power & time. Re-melting technology improves the product characteristics with higher & more with consistent mechanical properties.
- For example, inclusions or voids on finished tools found after machining means entire tool has to be scrapped, when such defects are detected after machining.
- The entire tool is scrapped leads wastage of entire machining process. Further tolerable voids of inclusions reduce life. In other words, the life time of tool will be higher with re-melted technology which has no/ minimal voids. The following example of specific cost are shown that relates to tool used in automotive industry manufacturing from **SKD 61** Grade steel.

Specific costs of a tool in automotive industry made from Tool steel

	Primary melted LF/VD VIM	Re-melted ESR	Twice Re-melted ESR - VAR
Material Costs	1.460 € (Rs.1 Lakh)	2.290 € (Rs. 2 Lakhs)	3.090 € (Rs. 2.5 Lakhs)
Tool manufacturing costs	52.600 € (Rs. 41 Lakhs)	52.600 € (Rs. 41 Lakhs)	52.600 € (Rs. 41 Lakhs)
Total tool costs	54.060 € (Rs.42 Lakhs)	54.890 € (Rs.43 Lakhs)	55.690 € (Rs.43.5Lakhs)
Life time (number of cycles)	100.000	150.000	255.000
Specific costs	0,54 € (Rs.43)	0,37 € (Rs.30)	0,22 € (Rs.18)

- Hence re-melted technology will leads to lower cost in the final end product.
- ESR process is state of art technology process, which is not only used in re-melting of high-tech alloys but also in steel making technology. Now high demanding requests for mechanical & chemical properties of steel, require more & more re-melting technology.
- Hence, industries like automotive, power, medical we require more ESR re-melted steel in future apart from aerospace & nuclear industries.

Advantages of ESR

- Removal of oxide and sulphide inclusions to a great extent and the remaining inclusions in the ingot are very fine and evenly distributed.
- Solidification of ingot structure almost equal to Vacuum Arc Re-melting (VAR), with no macro segregation and micro segregation.
- Uniform mechanical properties in longitudinal and transverse directions.
- Density of ingot is close to theoretical density and significant reduction of voids
- Due to formation of slag skin round the ingot ,the surface is smooth and no conditioning is required before forging
- Ingot sections such as square, polygonal ingots are also be made other than round ingots.
- No gas pick up from atmosphere due to protective argon atmosphere
- Close control of reactive elements like Aluminium, Boron, rare earth elements etc.

SUNFLAG (ESR)

ESR 1 Specification:

- Max ingot dia : 1030 mm
- Max. Ingot length 3500 mm
- Ingot weight 22000 Kg

ESR 2 Specification:

- Max ingot dia : 350 mm
- Max ingot length 2400 mm
- Max Ingot weight 1800 Kg

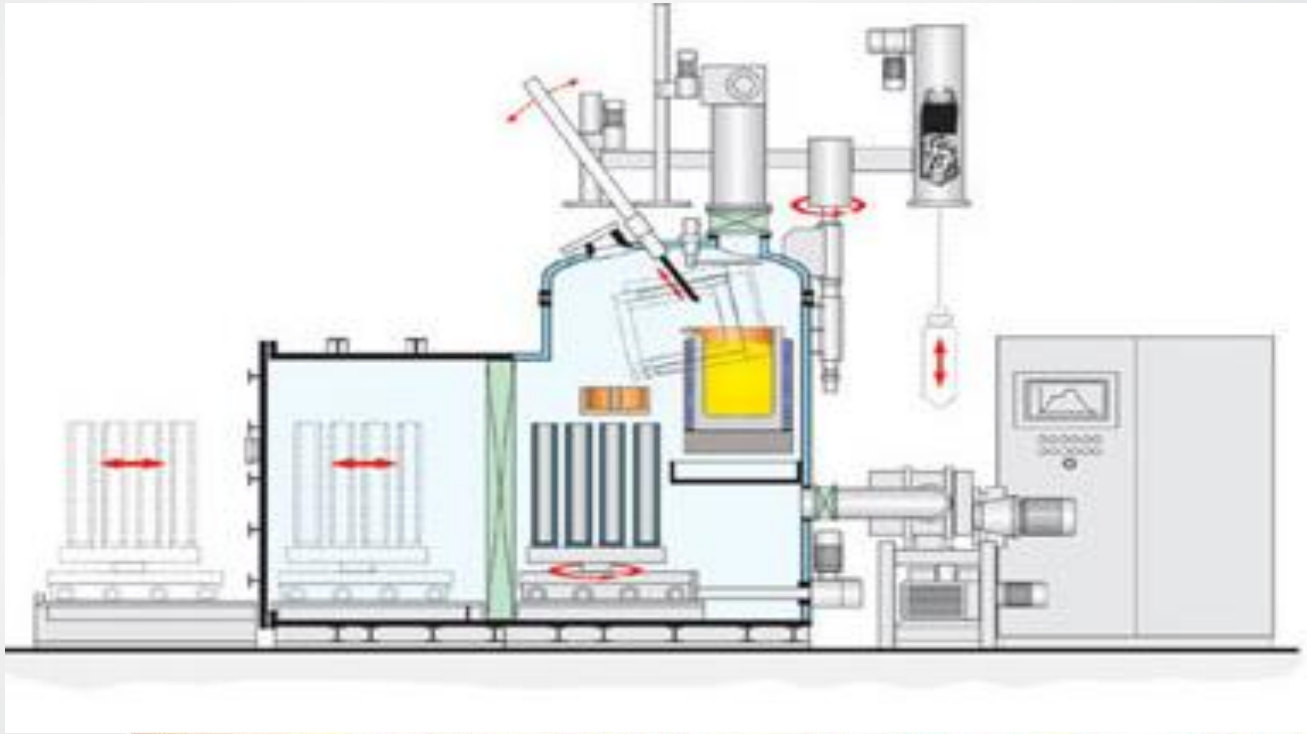
Salient features of Sunflag ESR

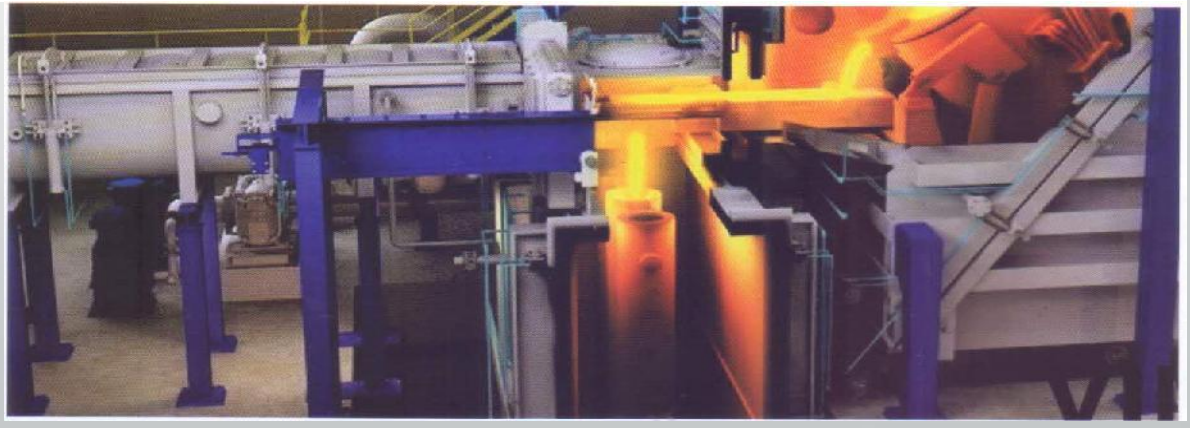
- Furnace is equipped with automatic feed control system
- Real time melt control system for complete auto furnace operation by defined melt recipe
  - **automatic start phase of furnace by a recipe defined power / time profile**
  - melt rate control maintain a recipe defined melt rate or melt power profile over consumed electrode weight
  - **automatic hot topping by recipe defined power profile**
  - **recipe defined profile for electrode control feed system for start melt and hot topping phase**
- Operator interface and data acquisition system
- Furnace head is provided X-Y angular corrections of electrode positions and **total sealed system for argon atmosphere melting**
- **Fume exhaust and atmospheric protection hood system**
- Fully co-axial current system.

VACUUM INDUCTION MELTING (VIM)

Specifications:
Capacity: 6.5 TON

Max. melt temp 1680 deg C
Max. Ingot mould length 4650 mm
Ultimate Vacuum 1 x 10-3 m bar



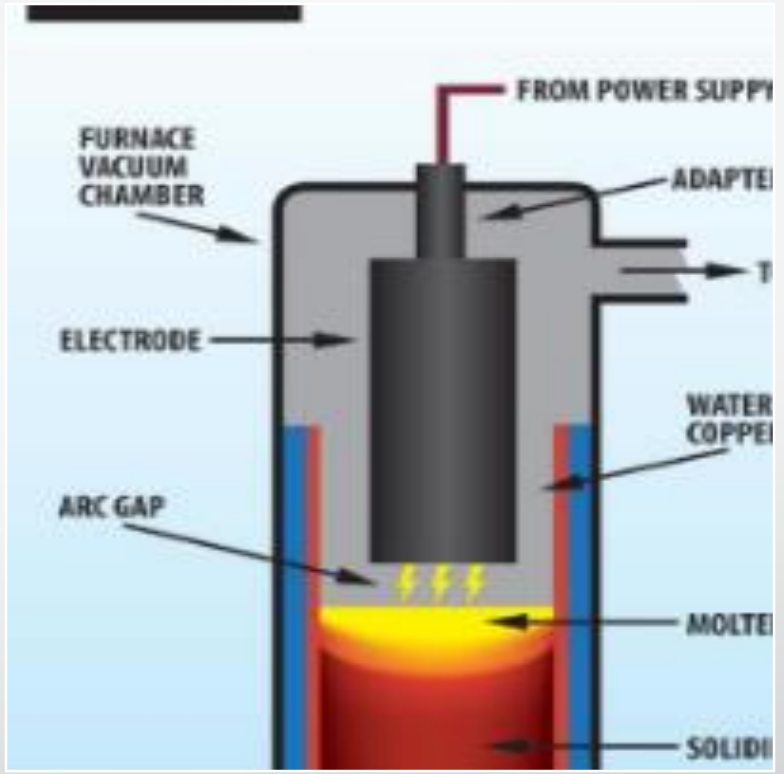


VACUUM ARC REMELTING (VAR)

SUNFLAG VAR

Specifications:

- Max. Ingot dia 450 mm
- Max Ingot weight 2200 kg
- Max ingot length 1775 mm



VACUUM ARC REMELTING (VAR)

DIFFERENTIATORS IN SUNFLAG GRADES

- **INTEGRATED PLANT**

The Primary material at Sun flag is produced through Iron Ore route and uses internal generated scrap only, hence negligible tramp elements such as Pb, Bi etc which gives enhanced life.

- **BRIGHT BAR FACILITY**

Our bright bar facility has got an online HT, UT and Eddy current testing which is unique in the country, which gives assured quality.

- **AUTO PHASED ARRAY UT**

Online auto phased array immersion UT, MPI, DPT tests ensures customers confidence on the product.

- **ONLINE ORDER TRACKING SYSTEM**

Customer can track online from order booking till order delivery including truck positioning (GPS)

Product Range for Hi-Tech Alloys

Type	Size Range (mm)
	Hot Forged
Bars	150 to 250 Dia
Rings	400 to 2000 (OD)
Discs	Upto 800 Dia
Cylinder	1000 (OD) – 4500 (Length)
	Hot Rolled
Bars	15 to 150 Dia
Flats	50 to 150 (W) & 5 to 34 (T)
Wire Rod Coils	5 to 38 Dia

Supply Condition

- Forged and Machined
- Annealed
- Hardened & Tempered
- Solution Annealed
- Aged

SUNFLAG HI TECH GRADES

S.NO.	SUPER ALLOYS	EQUI. GRADE	Fe	Ni	Cr	Mo	Co	Cu	Ti	C	Mn	Al	Others
	IRON BASED												
1	SUNR MDS	INCOLLOY DS	Bal.	38	18		18	0.5	0.2	0.1			Si 2.1
2	SUNR 800/800H	INCOLLOY 800/800H	46	32	21				0.38				
	NICKLE BASED												
1	SUN P600	INCONEL 600	8		15.5								
2	SUN P76	NIMONIC 76	4	75	19.5			0.4					
3	SUN P80A	NIMONIC 80A		75	21			2.45					
4	SUN P90	NIMONIC 90		59	19.5		19	2.5					
5	SUN P690M	INCONEL 690M	7-11	58 min	27-31			0.5	0.6	0.05	0.5		B 0.006, S 0.015
6	SUN P740	INCONEL 740	0.7	bal	25	0.5	20		1.8	0.03	0.3	0.9	Nb 2
7	SUN P825	INCOLLOY 825	30	42	21.5	3		2.25	0.9	0.03	0.5	0.1	
8	SUN P750	INCONEL 750X	7	73	15.5			0.25	2.5	0.04	0.5	0.7	Nb 0.95
9	SUN P625	INCONEL 625	2.5	61	21.5	9			0.2				Nb 3.15-4.15
10	SUN P718	INCONEL 718	18.5	52.5	19	3.05		0.15	0.9	0.04	0.18	0.5	Cb+Ta 5.13
11	SUN P82	INCONEL 82	3	bal	20				0.55		3		Nb 2.5
12	SUN PC276	HASTE ALLOY C276	5	62	0.6	28				0.02	1		V 0.3
13	SUN P617	INCONEL 617		44.5	23	9	13					1	B 0.006
14	SUN P706M	INCONEL 706	40	41.6	16	0.5	0.5		1.75				
15	SUN RA286	A 286	53	26	15	1.24			2.15		1.4		V 0.3

SUPER ALLOYS	EQUI. GRADE	Fe	Ni	Cr	Mo	Co	Cu	Ti	C	Mn	Al	Others
COBALT BASED												
SUN B605	INCONEL 605		10	20		BAL				1.5		W 15

SUNFLAG HI TECH GRADES

S No			Fe	Ni	Cr	Mo	Co	Cu	Ti	C	Mn	Al	Others
	SPECIAL STEEL												
1	SUN V250	MARAGING 250		18		4.8	8.5		0.4			4.2	
2	SUN V174	17-4PH	0.07	4	16.5			4					
3	SUN V155	15-5PH	0.07	5	15			4	0.8				
4	SUN V11-10	11-10PH	0.03	10	11	2							
5	SUN V904L	AVESTA 904L	0.02	25	19.5	4.5							
6	SUN V138	13-8Mo		8	12.5	2.3				0.05		1.1	
	HEATING ELEMENT ALLOYS												
1	SUN HEAT80	NICROME 5		80	20								
2	SUN HEAT60	NICROME 3		60	40								
	SOFT MAGNETIC IRON												
1	SUN MAG36B	PERM ALLOY D	Bal.	36									
2	SUN MAG48B	PERM ALLOY B	Bal.	48									
3	SUN MAG78	MUMETAL	Bal.	78									
	CONTROLLED EXPANSION ALLOYS												
1	SUN CE36	INVAR	Bal.	36									
2	SUN CE42	N42	Bal.	42									

Thank You