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*Maximizing steel productivity through
technology and service leadership*



Maximizing Steel Productivity Through Technology and Service Leadership

GrafTech International Ltd. is the leader in the carbon and graphite industry because we focus on maximizing our customer's bottom line and providing unparalleled support for their business, while developing cutting edge technology that sets the standard in the steel industry. From the very beginning of the company in 1886 through today, we have worked in close partnership with our steelmaking customers by focusing on transforming their needs into products and services. Our knowledge base in the steelmaking process is unequalled in the graphite electrode industry and is the key to our unmatched technical service.

GRAFTech

GrafTech International Ltd.

The National Carbon Company, founded in 1886, later became the Carbon Products Division of Union Carbide Corporation, and more recently UCAR® Carbon Company, Inc. In 2002 we became part of our holding company, GrafTech International Ltd. Though our name has changed a few times over the years, our commitment to our customers has not.

Our vision is to enable customer leadership better and faster than our competition, through the creation, innovation and manufacture of carbon and graphite material science based solutions.



Throughout the last century and into the 21st century, GrafTech's aggressive and impressive research and development record have led to revolutionary innovations in graphite technology which has increased productivity for our customers. GrafTech is proud of our strong commitment to our customers to provide the necessary competitive advantage to maximize productivity. Technical and service leadership is the foundation of our business.



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Technical Leadership

Since 1886, GrafTech has commercialized cutting edge technology that has revolutionized steelmaking in an EAF. The world's largest graphite and carbon research and development facility in Parma, Ohio is the center of many technical "firsts" in the industry. Our innovations result from the expertise of our scientists and engineers and our extensive global knowledge base of the industry. GrafTech has the most intellectual property in graphite and carbon science in the industry.

For example, for more than 20 years GrafTech International Ltd. has been using analytical, statistical, and finite element modeling to understand and improve the performance of graphite electrodes in an arc furnace environment. Our modeling efforts have included optimization of the design of the electrode joint and determination of the impact of graphite properties and furnace operation on electrode performance. The end result is better performing technology that enables better steelmaking productivity.



GrafTech's many innovations have revolutionized EAF steelmaking

1950's Introduction of chemical locking system (PRF) to prevent joint loosening.

1960's First commercial production of AGX™ 24" (600 mm) diameter graphite electrodes for ultra high performance applications. Introduction of pitch impregnation process to densify graphite electrodes.

1970's Introduction of Pre-Cet™ pins to improve safety and joint performance.

Commercialization of long pin technology.

Development and application of first Portable Arc Furnace Analyzer (PAFA).

1980's Introduction of Statistical Process Control (SPC) as a method to measure quality and produce consistently high quality products.

1990's First commercial production of AGX™ 30" (750 mm) diameter graphite electrodes.

2000 and beyond First commercial application of Apollo electrode system, designed to maximize productivity.

Commercialization of UCAR® ConneX™ Monitoring Systems that provide real-time and Internet based tracking.

Global Customer Technical Service

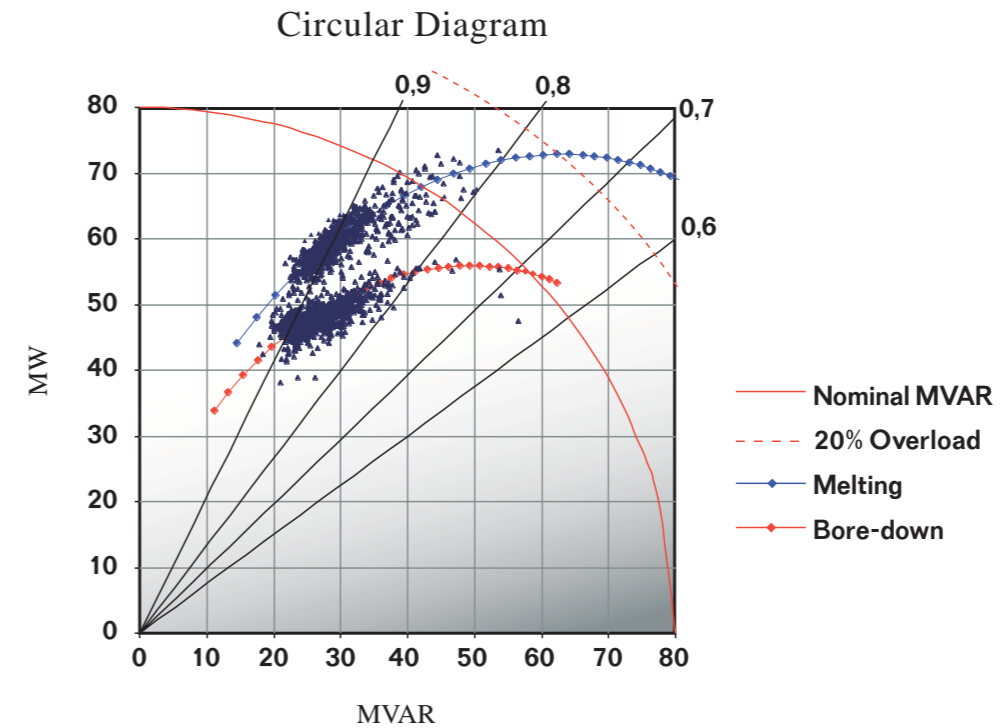
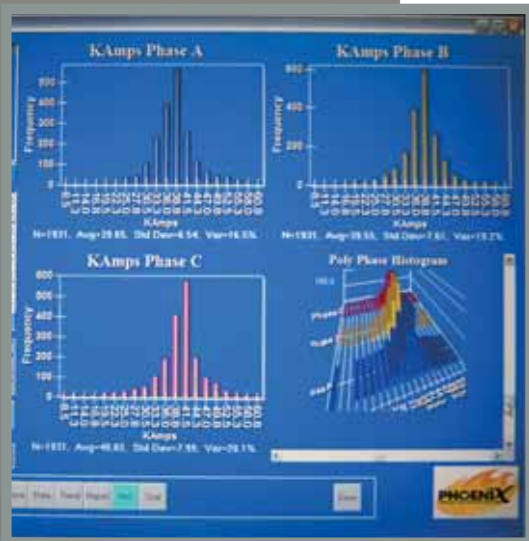
GrafTech continues to provide global technical service leadership through innovative state-of-the-art programs and value added services. Our expertise in analyzing furnace and electrode performance helps steelmakers to maximize their productivity.

ARC FURNACE OPTIMIZATION

Using the updated UCAR® PhoeniX™ Arc Furnace Analyzer (PAFA), high speed measurements and the ability to record auxiliary signals enables advanced electrode regulation system diagnostics. Because connections are made on the primary side of the furnace transformer, 100% of EAFs can be accurately measured. The updated PAFA samples 32 analog and 32 digital channels. With our exclusive analytical programs and global expertise, arc furnace electrical operation will be optimized.

The following specific services are available using the PhoeniX™ Arc Furnace Analyzer:

- Power optimization
- Meter verification
- Phase sequence
- Line reactance
- Short circuit reactance
- Phase balancing
- Power curves – circular diagrams
- High speed measurement and Fourier analysis
- Regulation checks
- Unique DC EAF expertise



OPTIMIZATION OF ELECTRODE PERFORMANCE

Analysis of the factors affecting electrode performance to optimize consumption.

Electrode Handling

The way in which the electrodes are handled and jointed can have a significant impact on the performance – a review of practices by your GrafTech representative could help prevent unnecessary electrode usage.

Time Utilization

The key factor in the oxidation component of electrode consumption is TIME. An independent review of your operation could identify savings of crucial minutes of power-off time that will not only reduce electrode consumption but also aid production.

Chemical Energy

Efficiently used chemical energy produces reaction and energy transfer where required in the furnace. Inefficient chemical energy reacts with electrode deltas and heats up the fume system.

Electrode Spray Cooling

Well-maintained electrodes spray cooling can reduce consumption by 5%-10%.

Power Program and Electrodes Regulation

An optimized power program and good regulation performance both have the effect of increasing average MW and reducing power-on time, thus minimizing tip consumption.

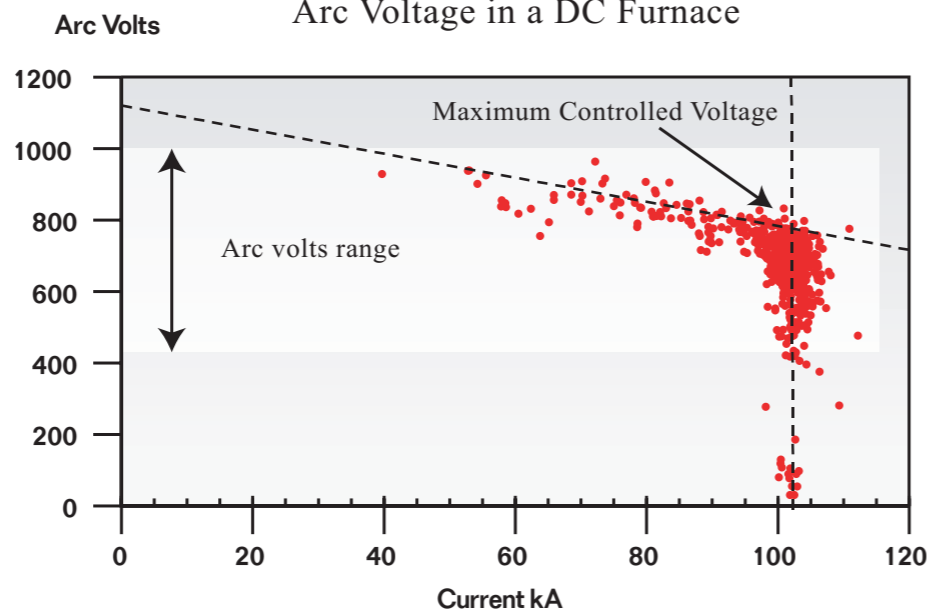
Foaming Slag Practice

A good foaming slag practice will help to minimize electrode consumption by stabilizing the electrical operation and giving beneficial furnace atmosphere conditions.

Product Selection

Selecting the correct grade and size of electrodes to suit the application will also minimize consumption.

Arc Voltage in a DC Furnace



Global Customer Technical Service

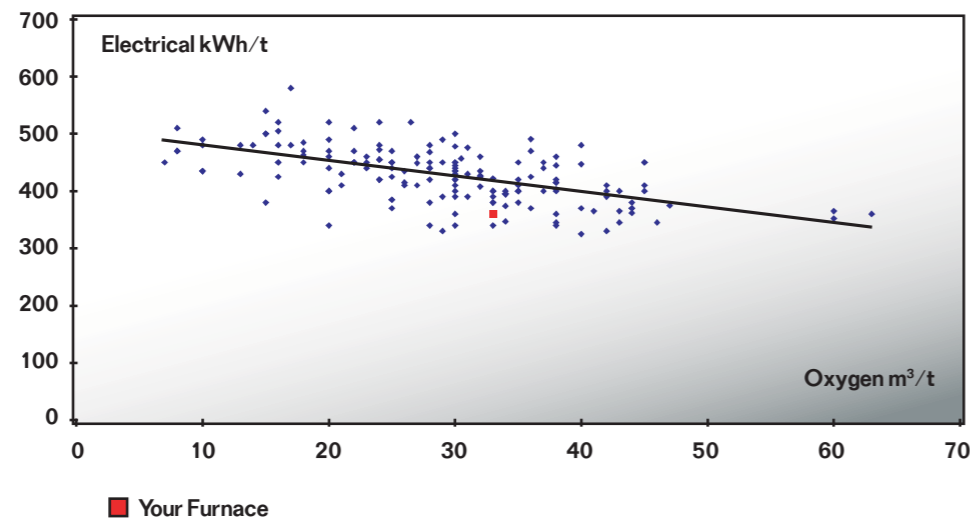
EAF BEST PRACTICES

Through our close and confidential relationship with customers operating more than 2000 electric arc furnaces in over 80 countries, we have an unparalleled view of arc furnace performance through our Technical EAF Database. Using this tool we are able to offer the following services:

- Comparative analysis through benchmarking
- Advise and training on Industry Best Practices
- Total energy audits



Benchmarking Analysis Electrical Energy versus Total Oxygen



TRAINING PROGRAMS

With our global exposure to practices in the steel industry we are able to offer training programs for your personnel to improve their knowledge and understanding of EAF & LMF operations. Subjects offered include:

- Electrode handling
- Modes of graphite consumption
- EAF benchmarking
- EAF productivity
- Total energy utilization
- Ladle furnace operation
- Electrical principles
- Chemical energy
- EAF raw material
- Oxygen practices
- Inventory management



TECHNOLOGY SEMINARS

We offer customized seminars for customer groups focused on subject areas of interest.

EQUIPMENT CONSULTATION

Our global presence gives us an independent overview of all EAF equipment and technology. We can assist you in the planning stage of your new project by discussing:

- Equipment selection
- Productivity capability and planning
- Design layout
- Start-up services

TECHNICAL LITERATURE

By utilizing our own world-class library we are able to provide the following literature services:

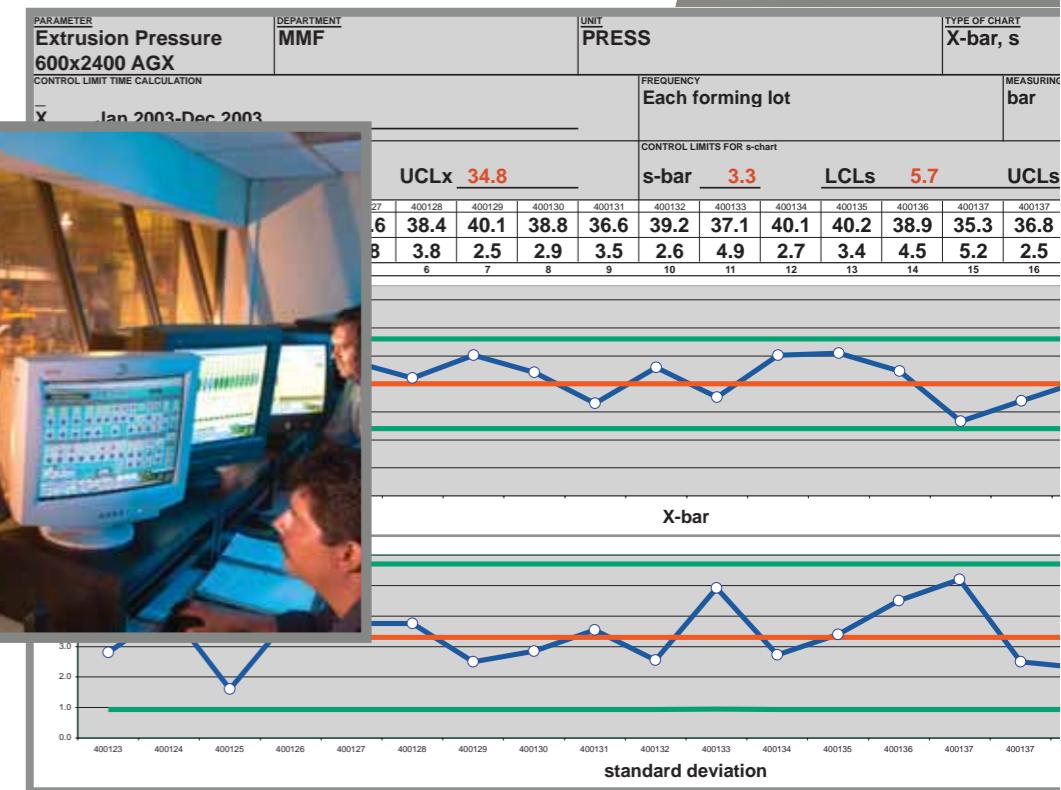
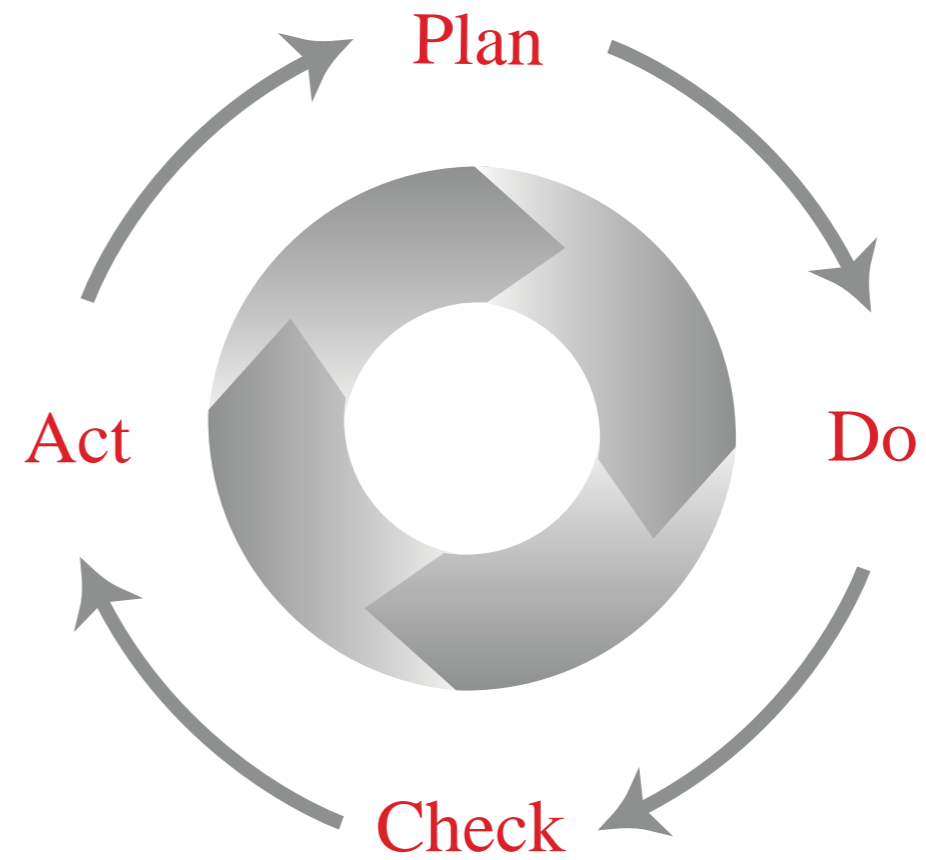
- Papers published by UCAR®
- Papers published by other industry experts
- Customized literature search conducted by our team of information researchers



GrafTech Global Quality

We consider sustained customer satisfaction the ultimate measure of product and service performance. Therefore, GrafTech's stringent quality system focuses on customer's needs and satisfaction. It is powered by statistical process control to minimize product variation and the Plan-Do-Check-Act cycle for timely performance improvement.

- Our Arc Furnace Technology engineers analyze customer applications and requirements – current and future – and feed them into our R&D systems. This enables us to optimize today's electrode performance and model next generation technology.
- R&D uses material science to translate customer applications and requirements into raw material, processing and testing Best Practices. This key Know-How ensures that all of our manufacturing locations utilize the latest process technology.
- Manufacturing focuses on Best Practice procedures and targets. Process and product variation is minimized through extensive use of statistical process control.
- Customer Technical Service engineers provide electrode use Best Practices to assure optimum graphite electrode performance.
- GrafTech employs strategic management techniques to achieve optimal manufacturing capability and global quality. We utilize ISO 9000 standards and statistical process control throughout all levels of the organization to assure our success.



Graphite Electrode Properties

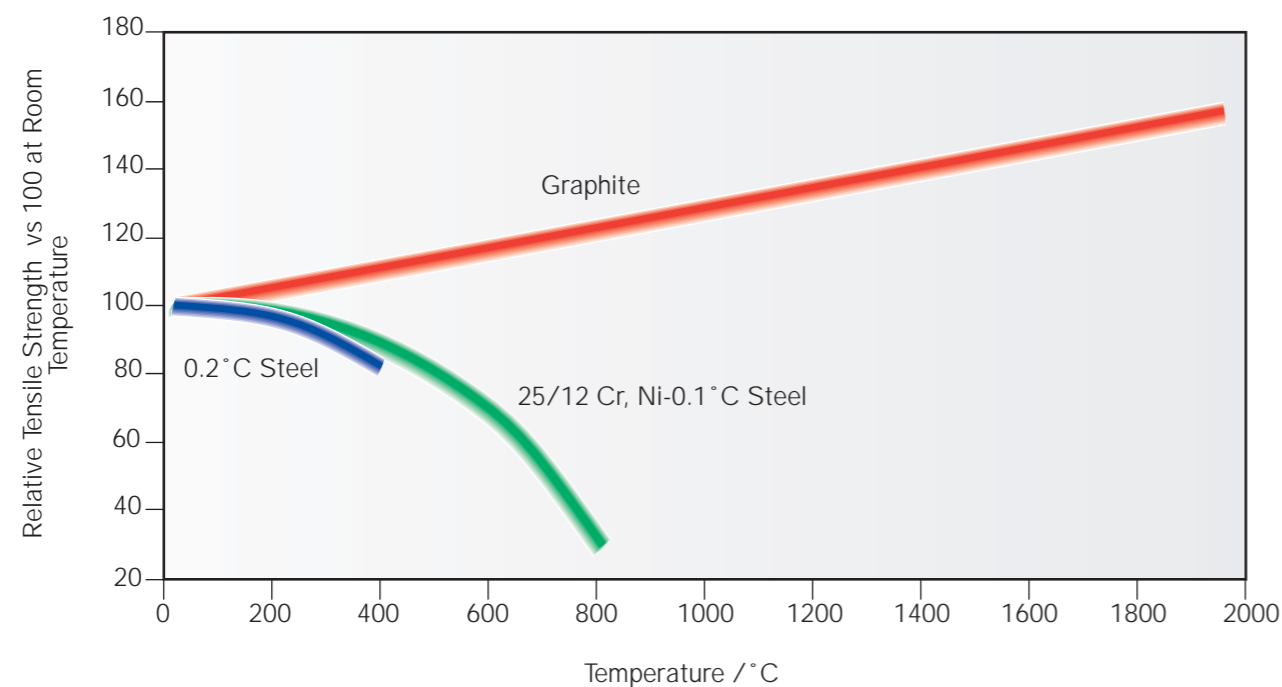
Graphite Electrode Properties

Property	Units	Electrode Diameter				
		250 - 400 mm, 10" - 16"		450 - 600 mm, 18" - 24"		650 - 750 mm, 26" - 28"
		AGR	AGX™	AGR	AGX™	AGX™
Bulk density	g/cm ³	1.55 - 1.65	1.65 - 1.75	1.56 - 1.66	1.65 - 1.74	1.67 - 1.75
Specific resistance	μΩm	6.0 - 8.0	4.5 - 6.0	5.5 - 7.0	4.1 - 5.5	4.0 - 4.9
Flexural strength	MPa	6.0 - 12.0	8.0 - 15.0	5.0 - 12.0	7.0 - 13.0	8.0 - 13.0
	PSI	900 - 1800	1200 - 2200	600 - 1300	1000 - 1900	1000 - 1800
Coefficient of thermal expansion	x10 ⁻⁶ /°C	0.5 - 1.5	0.2 - 1.4	0.2 - 0.8	0.15 - 0.6	0.2 - 0.5

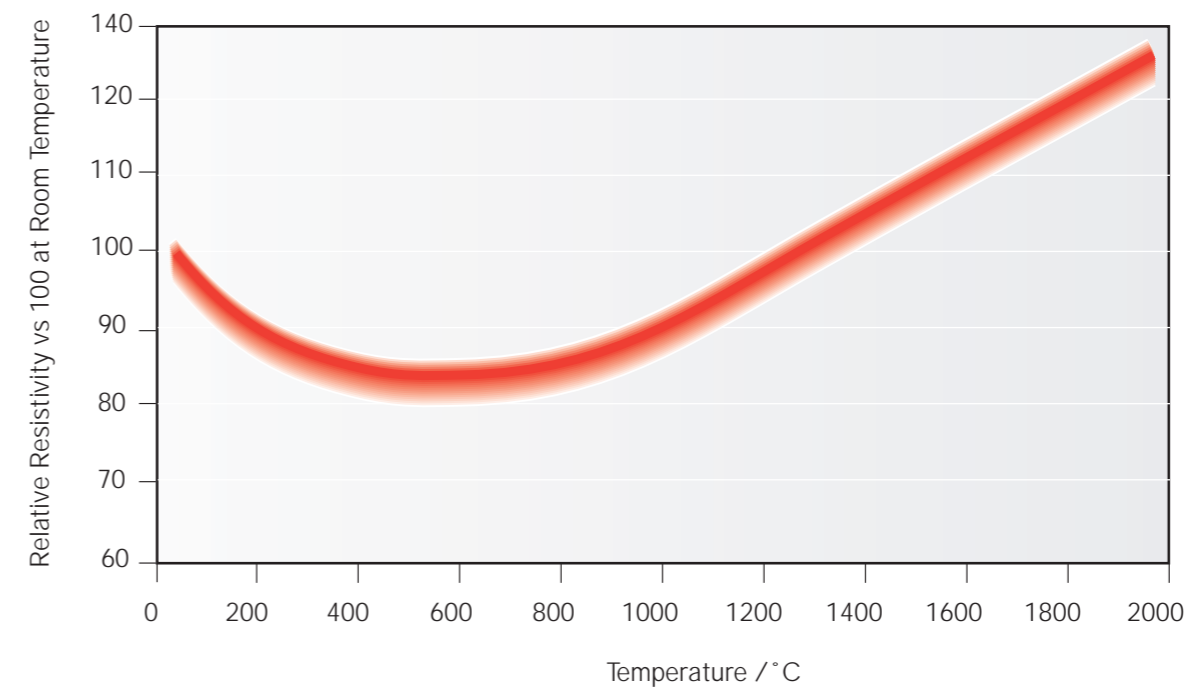
Connecting Pin Properties

Property	Units	Connecting Pins
Bulk density	g/cm ³	1.73-1.86
Specific resistance	μΩm	3.4-4.5
Tensile strength	MPa	12.4-20.0
	PSI	1800-2000
Coefficient of thermal expansion	x10 ⁻⁶ /°C	0-0.3

Relative Tensile Strength of Graphite as a Function of Temperature



Relative Resistivity of Graphite as a Function of Temperature



MAIN PROPERTIES

Bulk Density

A measurement of weight per unit volume. A higher bulk density will generally be reflected in improved mechanical properties.

Specific Resistance

The electrical resistance of a unit length of graphite. One of graphite's useful properties is that electrical resistance does not increase strongly with temperature. Up to 1400°C, the electrical resistance is lower than it was at room temperature.

Flexural Strength

The maximum stress which the material will withstand before rupture in bending (also called Bending Strength or Modulus of Rupture). Higher flexural strength in electrodes will generally result in lower electrode breakage frequency.

Note: As graphite is a brittle material, GrafTech uses the ASTM 4-point bending test, which gives more reliable results but values about 25% lower than the 3 point method used by some graphite suppliers.

Tensile Strength

A measurement of pure tensile force per unit area required to cause rupture by pulling apart. Higher tensile strength in pins will generally result in lower pin breakage frequency. Graphite's strength characteristics increase significantly with temperature.

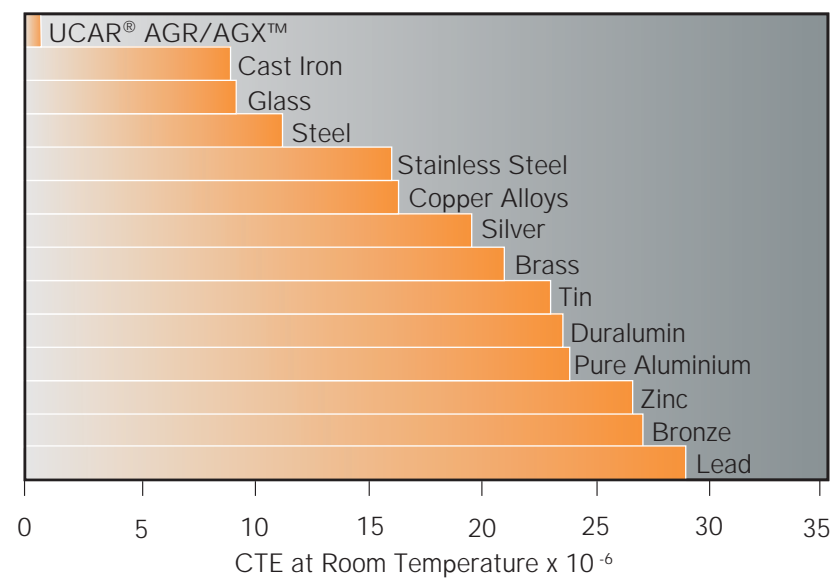
Graphite Electrode Properties

Coefficient of Thermal Expansion (CTE)

A measurement of the increase in length per unit length per degree rise in temperature. Lower CTE will give better resistance to thermal shock. Also, CTE compatibility between the graphite electrode and the connecting pin is important for satisfactory performance of the electrode joint.



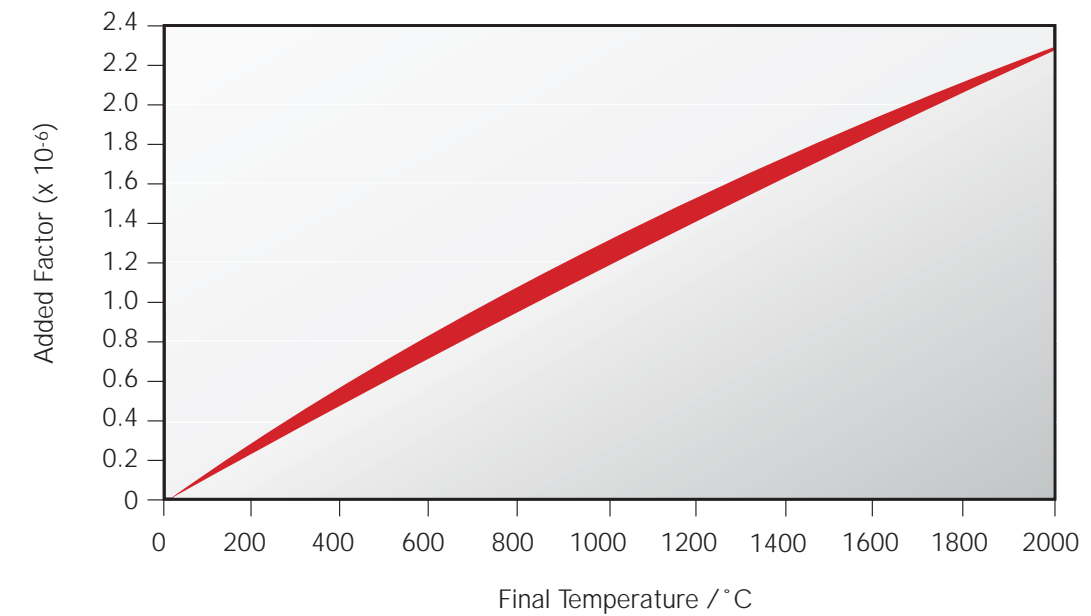
CTE at Room Temperature Compared to Other Materials



Change in Graphite CTE with Temperature

The change in CTE with temperature is about the same for all graphite at high temperature. The mean linear CTE between room temperature and any final temperature can be obtained from the following formula.

$$\text{CTE at } T^{\circ}\text{C} = \text{CTE at } 20^{\circ}\text{C} + \text{Added factor}$$



Testing Methods

Property	Method
Bulk density	ASTM C-559
Flexural strength	ASTM C-651
Tensile strength	ASTM C-749
Specific resistance	ASTM C-611
Coefficient of thermal expansion	PATE

PATE is a UCAR invention for accurately measuring the coefficient of thermal expansion.

Ash Content

UCAR® Graphite Electrodes typically have less than 0.1% impurities, and do not contain elements harmful to steelmaking.

Graphite Electrode Selection

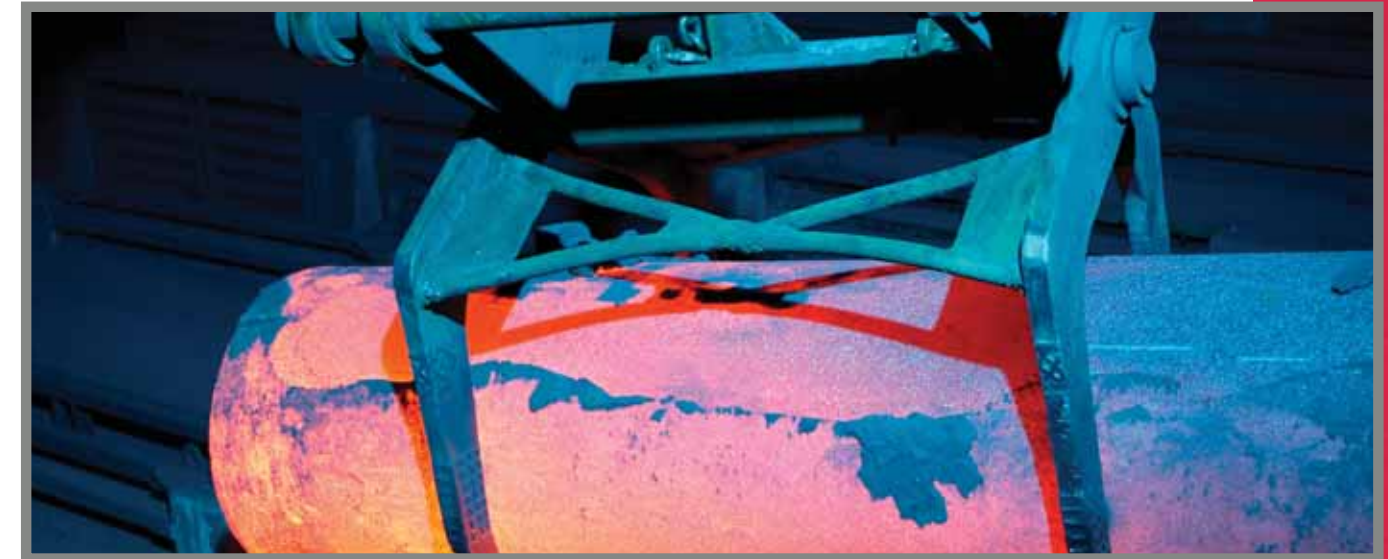
The following operating considerations must be addressed before selecting the electrode size and grade for a particular application.

- Production / Productivity Goals
- Furnace Design
- Steel Type and Grade
- Charge Material
- Charging Practice
- Power Level
- Current Level
- Slag Practice
- Burner/ Oxygen Practice
- Water Spray Rings
- Fume Control System
- Graphite Electrode Consumption Goal

GRAPHITE ELECTRODE SELECTION GUIDE (Metric)

Select Electrode Diameter			Electrode Length Options				Pin Options						
	Min	Max		Min	Max	Typical Weight of PRE-CET™ Electrode	IEC Designation	Diameter X Length	Threads per 25.4mm				
mm	mm	mm	mm	mm	mm	kg		mm					
250	251	256	1500	1490	1650	140	152T4N	152.40 x 190.50	4				
			1800	1745	1905	160	155T3N	155.57 x 220.00	3				
300	303	307	1800	1745	1905	230	155T3N	155.57 x 220.00	3				
							177T3N	177.16 x 270.90	3				
							177T4N	177.80 x 215.90	4				
							177T3N	177.16 x 270.90	3				
350	352	357	1800	1745	1905	310	203T4N	203.20 x 254.00	4				
							203T4L	203.20 x 304.80	4				
							215T3N	215.90 x 304.80	3				
							215T3N	215.90 x 304.80	3				
							222T4N	222.25 x 304.80	4				
400	406	409	1800	1745	1905	410	222T4L	222.25 x 355.60	4				
							241T3N	241.30 x 338.70	3				
							241T3L	241.30 x 355.60	3				
							241T3N	241.30 x 338.70	3				
							241T3L	241.30 x 355.60	3				
450	457	460	1800	1745	1905	510	241T4L	241.30 x 355.60	4				
							269T4L	269.88 x 457.20	4				
							273T3L	273.05 x 457.20	3				
							269T4L	269.88 x 457.20	4				
							269T4N	269.88 x 355.60	4				
							273T3N	273.05 x 355.60	3				
500	508	511	1800	1745	1905	640	273T3L	273.05 x 457.20	3				
							273T3L	273.05 x 457.20	3				
							298T4N	298.45 x 355.60	4				
							298T3N	298.45 x 372.50	3				
550	559	562	2100	2045	2210	910	298T4L	298.45 x 457.20	4				
							2400	2325	2515	1050	317T4N	317.50 x 355.60	4
							2700	2680	2870*	1180	317T4L	317.50 x 457.20	4
600	610	613	2100	2045	2210	1080	2700	2680	2870*	1410	355T4N	355.60 x 457.20	4
							2400	2325	2515	1250	355T4L	355.60 x 558.80	4
							2700	2680	2870*	1650	374T4N	374.65 x 457.20	4
650	660	663	2700	2680	2870*	1940	374T4L	374.65 x 558.80	4				
							700	711	714	2700	2680	2870*	1940
750	762	765	2700	2680	2870*	2070							

* Longer maximum length available to many 2700 mm customers



GRAPHITE ELECTRODE SELECTION GUIDE (English)

Select Electrode Diameter			Electrode Length Options				Pin Options		
	Min	Max		Min	Max	Typical Weight of PRE-CET™ Electrode	IEC Designation	Diameter X Length	Threads per inch
Inches	Inches	Inches	Inches	Inches	Inches	Pounds		Inches	
10	9.88	10.08	60	57	65	310	152T4N	6 x 7.5	4
			72	68.5	75	350	155T3N	6.125 x 8.66	3
12	11.92	12.08	72	68.5	75	510	155T3N	6.125 x 8.66	3
							177T3N	6.975 x 10.66	3
							177T4N	7 x 8.5	4
							177T3N	6.975 x 10.66	3
14	13.88	14.08	72	68.5	75	690	203T4N	8 x 10	4
							203T4L	8 x 12	4
							215T3N	8.5 x 12	3
							215T3N	8.5 x 12	3
							222T4N	8.75 x 12	4
16	16.00	16.12	72	68.5	75	900	222T4L	8.75 x 14	4
							241T3N	9.5 x 13.33	3
							241T3L	9.5 x 14	3
							241T3N	9.5 x 13.33	3
							241T3L	9.5 x 14	3
18	18.00	18.12	72	68.5	75	1130	241T4L	9.5 x 14	4
							269T4L	10.625 x 18	4
							273T3L	10.75 x 18	3
							269T4L	10.625 x 18	4
							269T4N	10.675 x 14	4
							273T3N	10.75 x 14	3
20	20.00	20.12	72	68.5	75	1410	273T3L	10.75 x 18	3
							273T3L	10.75 x 18	3
							298T4N	11.75 x 14	4
							298T3N	11.75 x 14.66	3
22	22.00	22.12	84	80.5	87	2010	298T4L	11.75 x 18	4
							298T4L	11.75 x 18	4
							298T4L	11.75 x 18	4
24	24.00	24.12	84	80.5	87	2370	317T4N	12.5 x 14	4
							317T4L	12.5 x 18	4
							317T4L	12.5 x 18	4
							317T4L	12.5 x 18	4
26	26.00	26.12	110	105.5	113*	3630	355T4N	14 x 18	4
							355T4L	14 x 22	4
							355T4L	14 x 22	4
28	28.00	28.12	110	105.5	113*	4270	374T4N	14.75 x 18	4
							374T4L	14.75 x 22	4
30	30.00	30.12	110	105.5	113*	4550	406T4N	16 x 23	4

* Longer maximum length available to many 110 inch customers

Graphite Electrode Selection

Your GrafTech Technical Service Engineer can help you decide which type of product best suits your existing or future needs. The standard grades can be refined to meet your special needs.

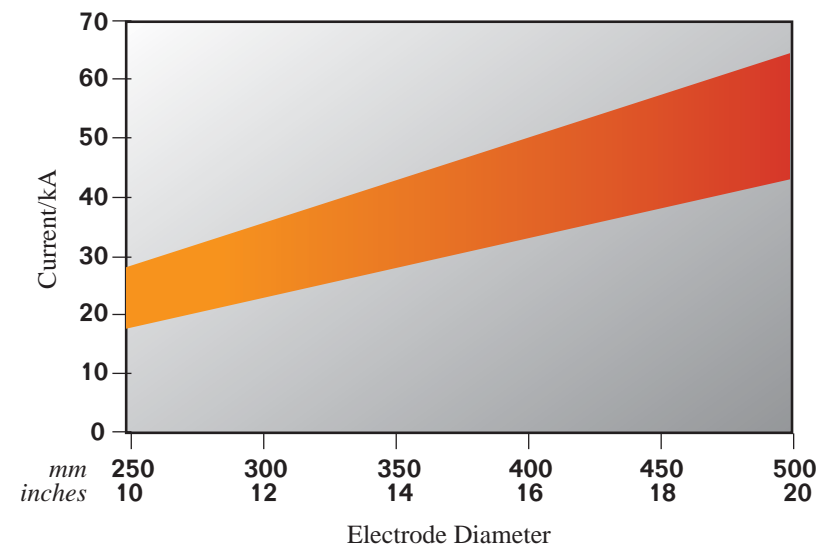
Grade AGX™:

A premium grade recommended for high power, ultra high power and DC furnaces operating under severe electrical, mechanical and/or thermal conditions. AGX™ is also recommended for ladle furnace applications.

Grade AGR:

A standard grade for applications where operating conditions are not severe.

Current Carrying Ranges for Ladle Furnace Applications



These are typical current carrying capacities as observed in present use of GrafTech electrodes around the world. More severe operating capacities and unusual applications may differ and require investigation by your GrafTech Technical Service Engineer to define a product to meet your requirements.



Current Carrying Ranges for Electric Arc Furnace

