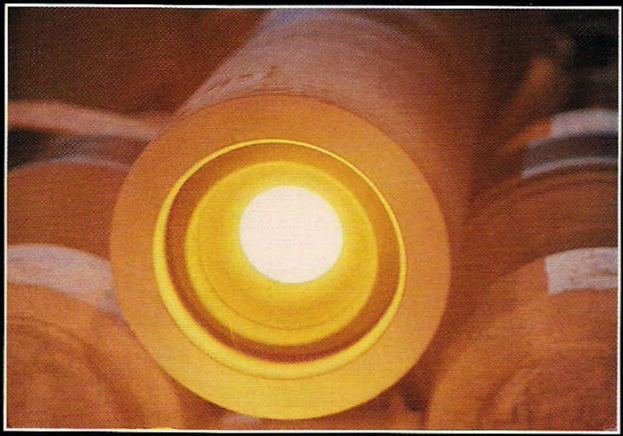
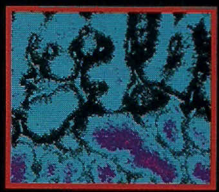
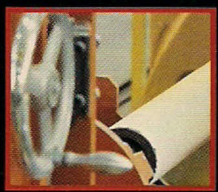
QUALITY PRECISION INNOVATION

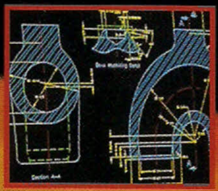
Kubota

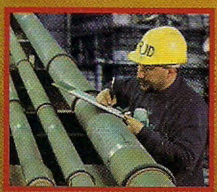
METAL CORPORATION











HEAT RESISTANT ALLOYS

Petrochemical coil undergoing strict final inspection prior to shipment

Introduction

Kubota Metal Corporation, Fahramet Division (KMF) has specialized in the centrifugal and static casting of high alloy, heat resistant steels for decades. Our advanced casting and fabrication abilities are here to serve your needs, whether your business is producing aluminium, copper, ethylene, hydrogen, magnesium, paper, steel or zinc.

Where resistance to high temperature is needed, we provide the engineered alloys, processes and the expertise that ensures the excellent performance our customers have come to expect from Kubota products.

Component service conditions are as diverse as the industries served. Stresses may be compressive, tensile, hoop, bending, cyclic or combinations of these. Atmospheres may be oxidizing, carburizing, or be highly corrosive due to compounds of sulphur, chlorine, vanadium or sodium. Component temperature may approach the melting point of some alloys or be subjected to abrasive wear by impact, sliding or gouging.

To meet this variety of conditions Kubota has developed an extensive range of heat resistant alloys. These may be simple variants of wrought stainless steel or highly alloyed proprietary materials. Since the choice of alloy affects the cost to you, the selection should be made after appropriate consideration of the component requirements.

The technical information presented in this brochure is designed to help you with the evaluation of cast, heat resistant alloys. Furthermore, it is intended to illustrate a few of the considerations that must be made to make an effective alloy choice for a particular application.

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If you have any questions or require further information contact your nearest representative or Kubota's head office in Orillia.

Common Applications of Kubota Heat Resistant Alloys

Alloy	Cracking Coils	Reforming Tubes	Coil Hangers	Outside Firebox	Furnace Rolls	Heat Treatment Fixtures	Radiant Tubes
KHR12C					✔	✔	✔
KHR20T		✔					
KHR24C		✔				✔	
KHR32C		✔		✔	✔	✔	
KHR35C		✔	✔		✔		
KHR35C HiSi	✔						
KHR35CL				✔	✔	✔	
KHR35CT		✔	✔				
KHR35CT HiSi	✔						
KHR35CW	✔						
KHR35H					✔	✔	✔
KHR35H HiSi	✔						✔
KHR35W	✔						
KHR40CM						✔	
KHR45A	✔		✔				
KHR45A LC				✔			
KHR48N			✔		✔	✔	✔
KHR48NCo			✔		✔	✔	✔
KHR48N HiSi						✔	✔
KHRS2			✔				✔
KHRS3		✔	✔		✔	✔	✔
KHRSA			✔		✔	✔	✔
UCX	✔						

KUBOTA WORLDWIDE

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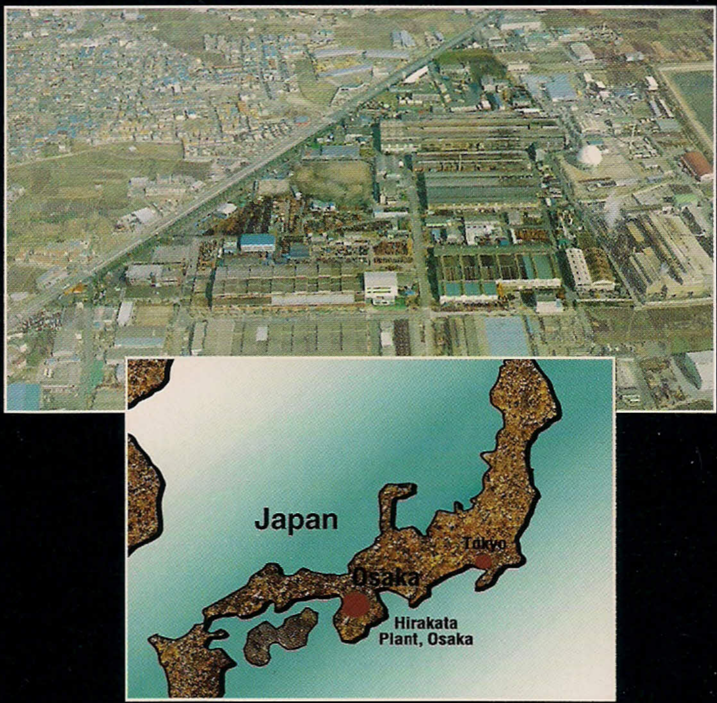


REGISTERED COMPANY ISO 9002 SGS

Kubota
METAL CORPORATION

KMF - 001 MAR 2000

Precision & Innovation

While this brochure cannot answer all of your questions, *KMF* SALES, ENGINEERING and METALLURGICAL staff are ready to supply you with any additional information or assistance that will help in the selection of the right material for your application.

Cast vs Wrought

The properties of cast heat resistant alloys differ significantly from compositionally similar wrought alloys. In some applications a cast material offers the better option; while in others, the opposite may be true. The following factors are important when faced with this choice:

The high temperature rupture strengths of the cast alloys are 2.5 to 3.5 times greater than those of the "equivalent" wrought materials, as illustrated by the comparisons in Table 1.

The higher elevated temperature strength of the cast alloys is primarily due to their high carbon content. Carbon in the wrought 300 series stainless steels is less than 0.25% compared with 0.3 to 0.6% carbon in the heat resistant cast alloys. The higher strength results from the greater amount of carbon retained in solid solution in the austenite and from large precipitated carbide phases.

The room temperature ductility of the cast alloys is lower than that of the wrought grades. Consequently, more care must be exercized in welding these materials, particularly after service exposure.

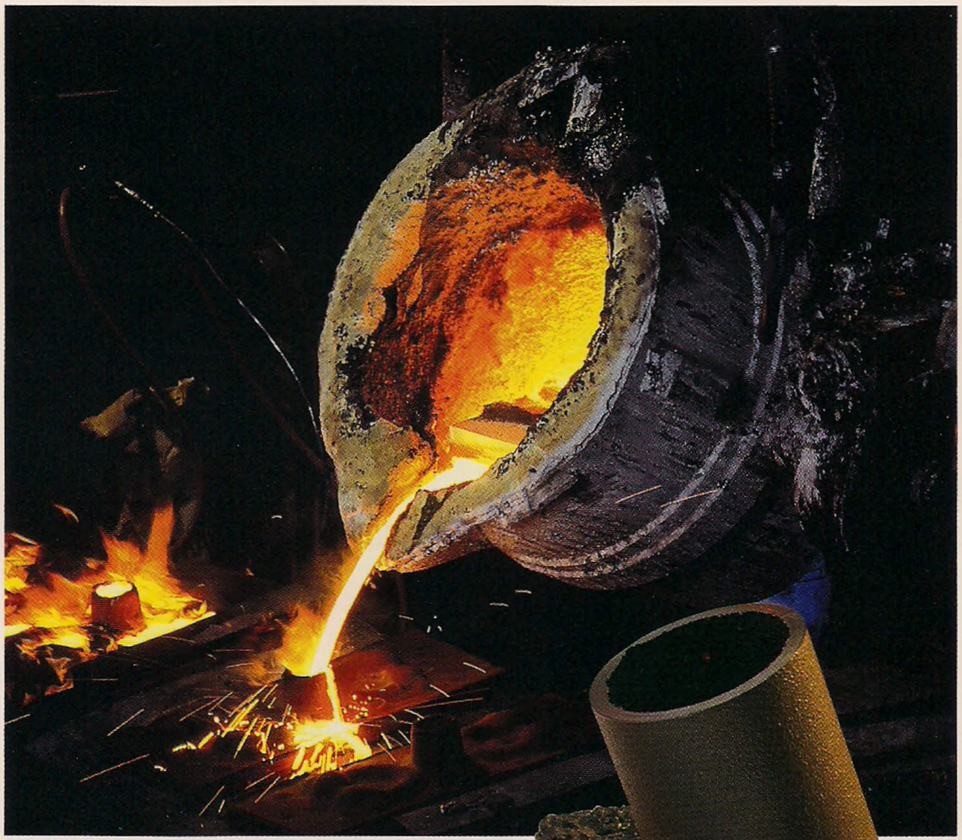
The compositions of standard cast alloys can be easily modified to optimize specific properties, such as rupture strength or carburization resistance. Unlike wrought alloys, where such changes are only feasible in large mill runs, these changes can be made to small individual heats of the cast alloys.

Because of greater design flexibility of castings, extensive weld fabrication can be either reduced or totally eliminated. All this combines to make cast heat resistant alloys a cost effective choice for many applications.

COMPARATIVE RUPTURE STRENGTH

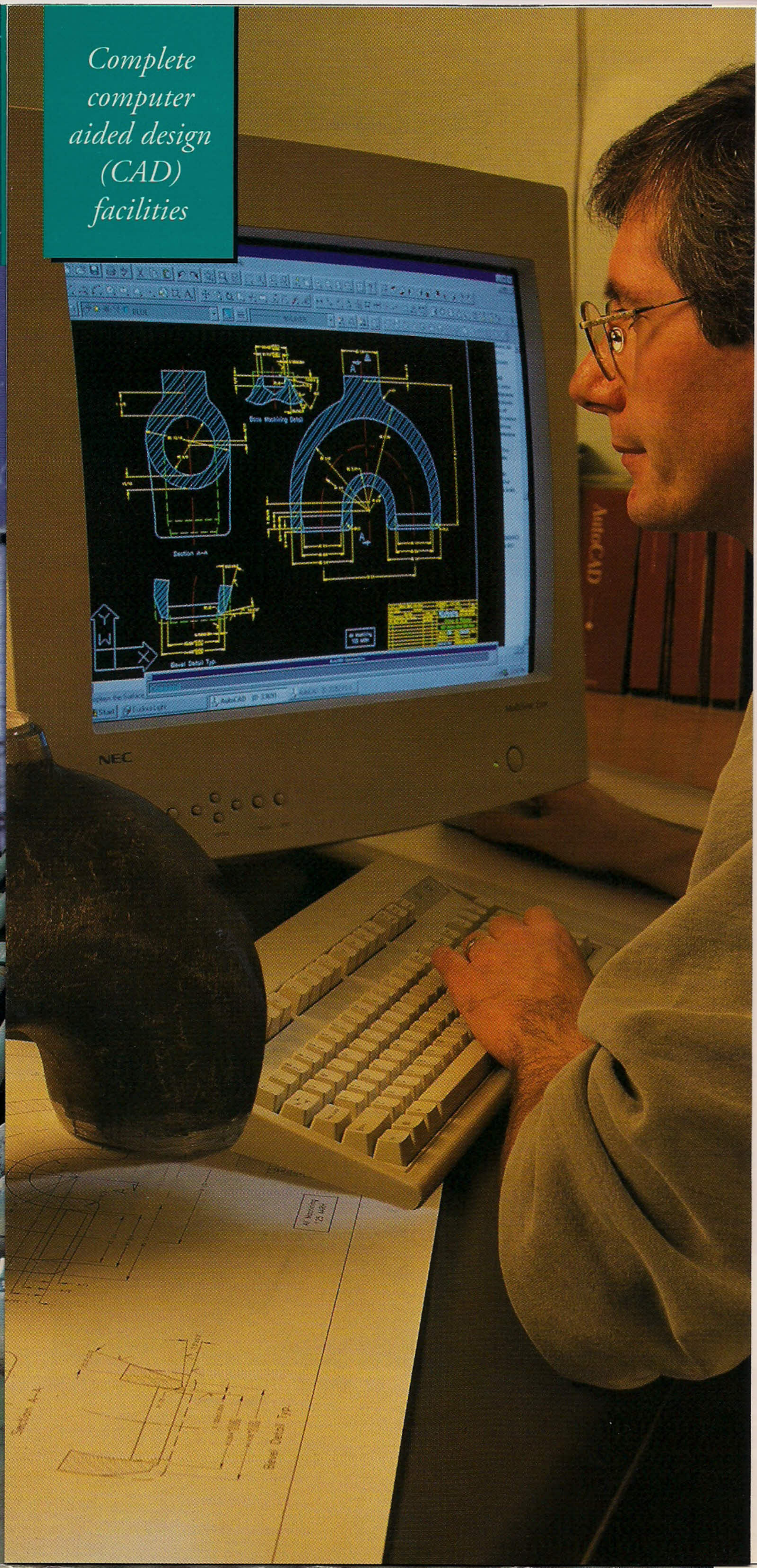
FORM	ALLOY	10,000 HOUR RUPTURE-STRESS (ksi)	
		1600 °F	1800 °F
Wrought	309	1.5	0.5
Cast	HH Type II	4.4	1.7
Wrought	310	1.5	0.5
Cast	HK 40	4.0	1.6
Wrought	330	1.7	0.6
Cast	HT	4.7	1.7

Table 1 Comparative high temperature creep rupture strength of equivalent cast and wrought heat resistant alloys.



Petrochemical components are cast using only high purity virgin materials and KMF foundry remelt.

Complete computer aided design (CAD) facilities



KHR Kubota Heat Resistant Alloys

The compositions and physical properties of many Kubota Heat Resistant alloys are listed in Table 2. In addition to these, *KMF* manufactures dozens of other heat resistant alloys not listed, including all standard Alloy Casting Institute (ACI) grades.

In general, these alloys are based on mixtures of nickel, chromium and iron, along with additions of modifying elements including aluminium, cobalt, molybdenum, niobium, rare earths, titanium, tungsten and zirconium.

Carbon is the single most important alloying element common to the heat resistant steels. For high strength alloys it is typically present in a range from 0.30 to 0.60%, but some special purpose alloys are cast with less than 0.20% carbon.

The major mechanical properties of the Kubota Heat Resistant alloys listed in Table 2 are summarized in Table 5. This incorporates: the 100,000 hour rupture and the 0.0001%/hour limiting creep stresses; room temperature and elevated temperature tensile properties. These properties are explained in greater detail in the sections that follow.

Inside flap:

Table 2 Compositions of Kubota Heat Resistant Alloys.
Figures 1 and 2

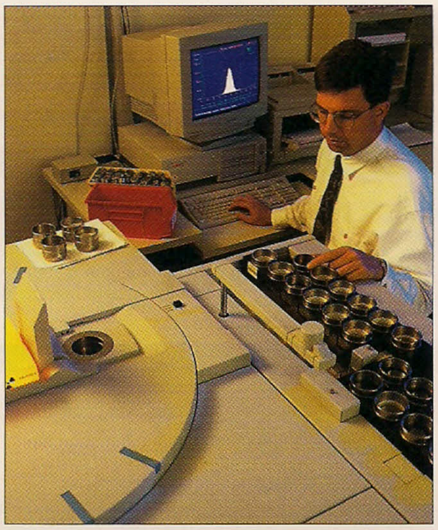
Cracking Alloys vs Reformer Tube Alloys

The majority of the capacity of *KMF* is devoted to the production of furnace coils for the petrochemical industry. The design and alloy selection for these coils is generally dependent on whether the coil is destined for hydrocarbon cracking service or hydrogen reforming service. Kubota makes a clear distinction between alloys for use in these two operations. This distinction is most often represented by the addition or absence of the suffix "HiSi", which stands for High Silicon, to the alloy name.

Silicon is an element that is critical for resistance to carburization, as will be described later, but is detrimental to high temperature strength and fatigue resistance. It is for this reason that Kubota considers "high silicon" and "low silicon" alloy versions to be entirely separate, distinct alloys. The mechanical properties of the two classes of alloys are therefore developed separately and published individually. The end user should beware of this difference and make minimum sound wall decisions accordingly.

The main distinction between the two types of alloys, therefore, is the tradeoff between strength and carburization resistance. Table 3 and Table 4 rank the two series of Kubota alloys based on several key material properties.

The transition region from a furnace to the outside atmosphere is a critical portion of any gas processing operation. Process tubes in this area are subject to severe thermal stresses due to temperature gradients and cyclical operation. For this region specially modified alloys have been developed which emphasize retained ductility and fatigue resistance over strength and corrosion resistance. Alloys for these applications usually have lower carbon and silicon compared to their purely heat resistant counterparts. Examples of such alloys are KHR32C, KHR35CL and KHR45A LC.



A simultaneous x-ray fluorescence (XRF) spectrometer and an optical emission spectrometer (OES) are used for control of product chemistry.

CRACKING TUBE ALLOYS

Alloy	Rupture Strength @ 2000 °F	Creep Strength @ 2000 °F	Carburization Resistance	Weldability	Total Score	Rank
KHR35C HiSi	63	41	33	50	187	4
KHR35CT HiSi	100	50	37	46	233	2
KHR35CW	61	35	37	42	175	5
KHR35H HiSi	65	47	33	42	187	4
KHR35W	76	47	35	42	200	3
KHR45A	87	49	100	42	278	1

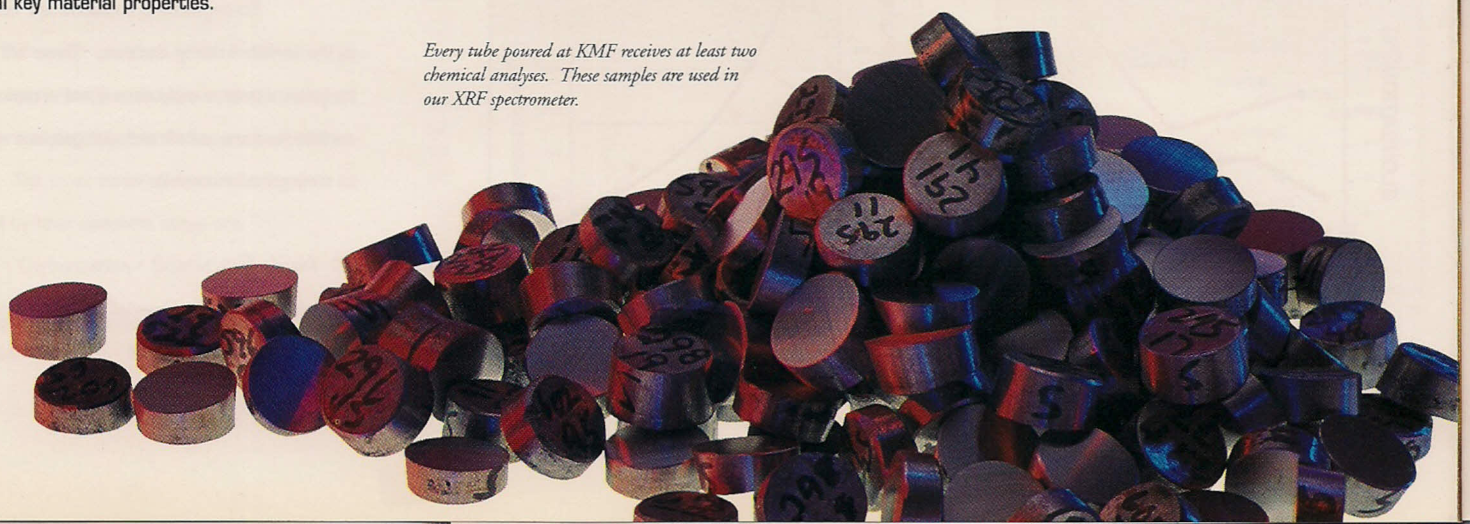
Table 3 Ranking of cracking tube alloys

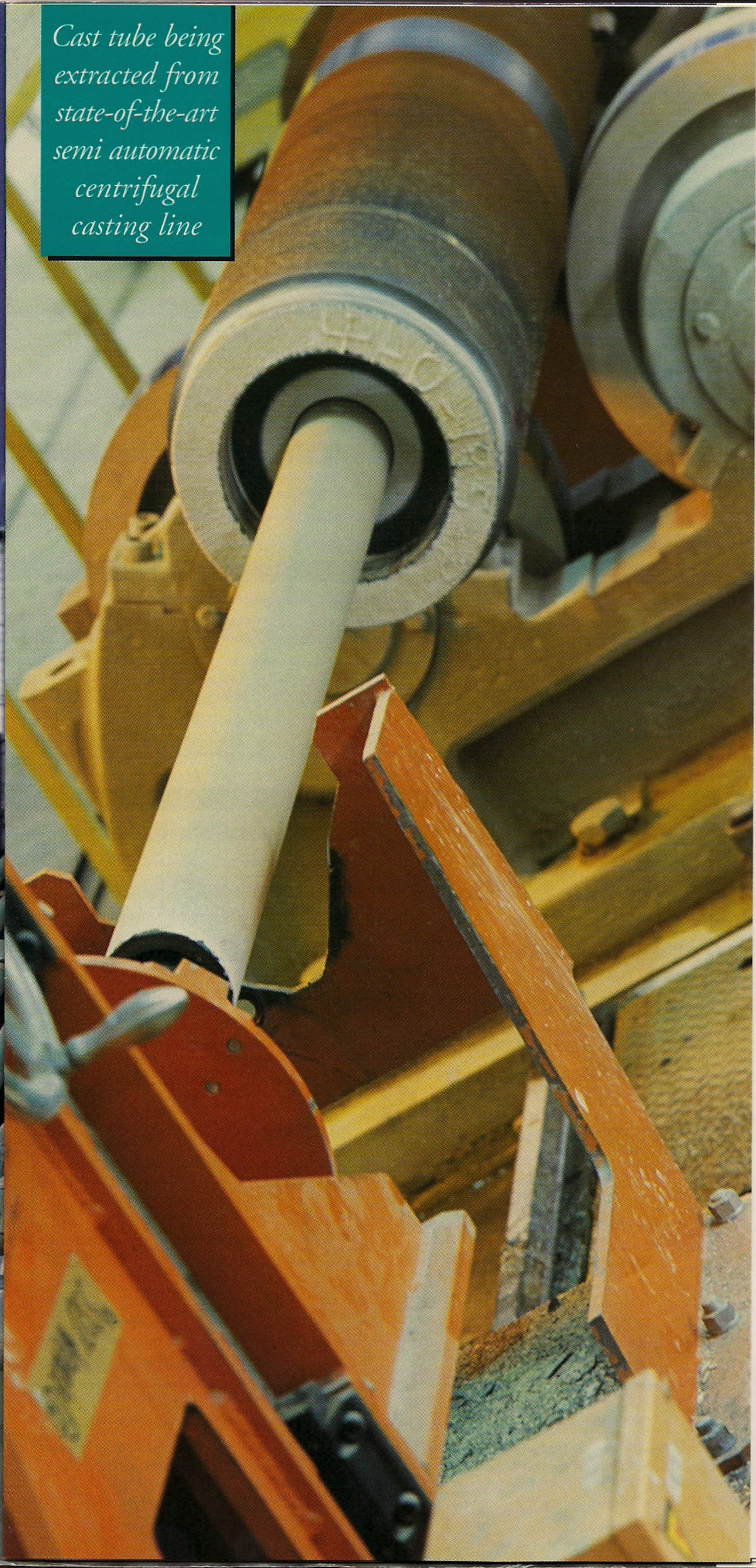
REFORMER TUBE ALLOYS

Alloy	Rupture Strength @ 2000 °F	Creep Strength @ 2000 °F	Oxidation Resistance	Weldability	Total Score	Rank
HK40	40	73	18	100	231	5
KHR20T	70	100	18	87	275	3
KHR24C	50	92	42	87	271	4
KHR35C	80	100	100	57	337	2
KHR35CT	100	100	100	52	352	1

Table 4 Ranking of reformer tube alloys

Every tube poured at KMF receives at least two chemical analyses. These samples are used in our XRF spectrometer.




Cast tube being extracted from state-of-the-art semi automatic centrifugal casting line

Creep-Rupture Strength

The average 100,000 hour rupture stresses and the 0.0001%/hour creep stress of the Kubota alloys are presented in Table 5. Long term stresses vary from the low load bearing values of simple grades such as KHR12C to highly alloyed Ni-Cr-W-Fe alloy KHRSA. Rupture strength is the stress required to produce rupture at a given time and temperature. Limiting creep strength is defined as the stress required to distort the material 1% in 10,000 hours at a given temperature. Figure 3 illustrates how the estimated life of a reformer tube changes with applied stress and temperature.

In terms of high temperature strength, KMF heat resistant alloys fall into two distinct groups, each of which may be related to total alloy content. The unmodified A.C.I. grades HC to HX form one strength group, as shown in Figure 4. These contain chromium, nickel and iron, plus small amounts of carbon, silicon and manganese. As total nickel and chromium increases above 30%, rupture strength increases and reaches a maximum at 60%Ni+Cr, or the HP grade. Additional nickel and chromium above a total of 60% does not raise strength any further. A distinctly different group of alloys with supplementary alloying elements are required for this purpose.

Strengthening additions are dominated by the carbide forming elements. These are niobium, tungsten, titanium, molybdenum and zirconium. Non-carbide formers, cobalt and nitrogen, are also used to strengthen materials.

Inside flap:

Table 5 Mechanical Properties of Kubota Heat Resistant Alloys.
Figures 3, 4, 5, 6

Manufacturing Technology

HP alloy is the base composition for several modified alloys including: KHR35C, KHR35H and KHR35W which are enhanced by the presence of niobium, molybdenum and tungsten, respectively. These alloys are commonly used in a service range from 1700 to 2050 °F (927 to 1121 °C). For higher operating temperatures from 1900 to 2200 °F (1038 to 1204 °C) the base alloy typically consists of 26-36% chromium plus 40-50% nickel. Among the high strength alloys of this type are KHR48N, KHR45A and KHRSA.

Kubota publishes standard information on its alloy mechanical properties in the "as-cast" condition. These properties, however, will change during service depending on the time, temperature, and corrosive environment of the operation.

The as-cast alloy retains a significant amount of carbon in solution. During exposure at temperatures between 1200 and 2000 °F (649 to 1093°C), this carbon precipitates out in the form of secondary or primary carbides. This process is called "aging". Aging of the material can result in a loss of room temperature ductility. Figure 5 shows how aging and carburization can affect the mechanical properties of an alloy.

Corrosion Resistance

Corrosion is a fact of life for heat resistant components. However, it can be controlled through appropriate alloy selection and component fabrication. The most common types of corrosion experienced by heat resistant alloys are:

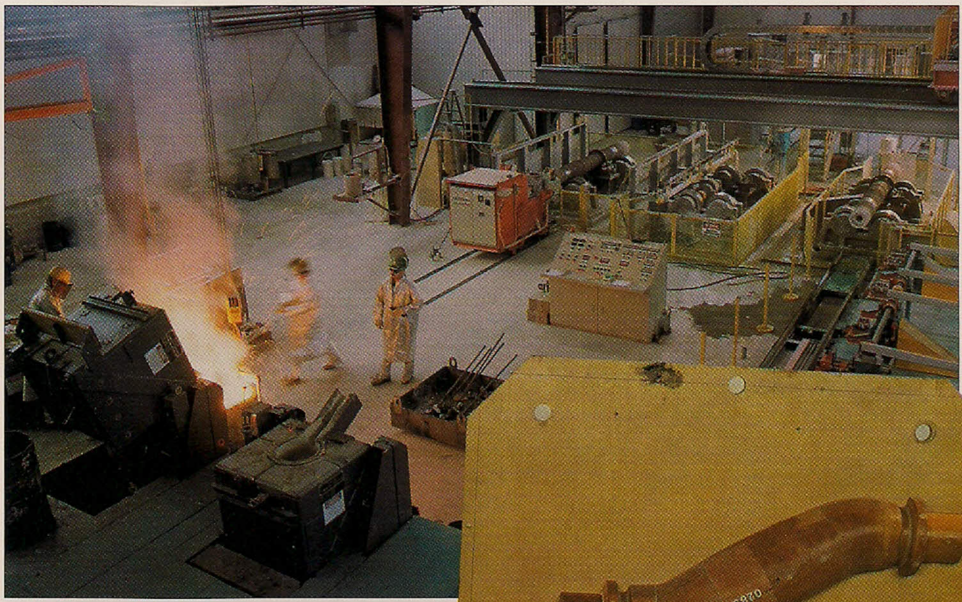
- Oxidation • Carburization • Sulphidation
- Nitridation • Halogen Corrosion • Corrosive Ash
- Molten Salt Corrosion • Molten Metal Corrosion

Heat resistant alloys normally form a protective surface oxide which acts to slow or prevent continuing corrosion attack on the base material. The most protective oxides will often contain large quantities of chromium oxide, and sometimes silicon and aluminium oxides. Since the metal elements for the oxide come from the base material, the more chromium or element of interest in the base metal, the more there will be in the surface oxide.

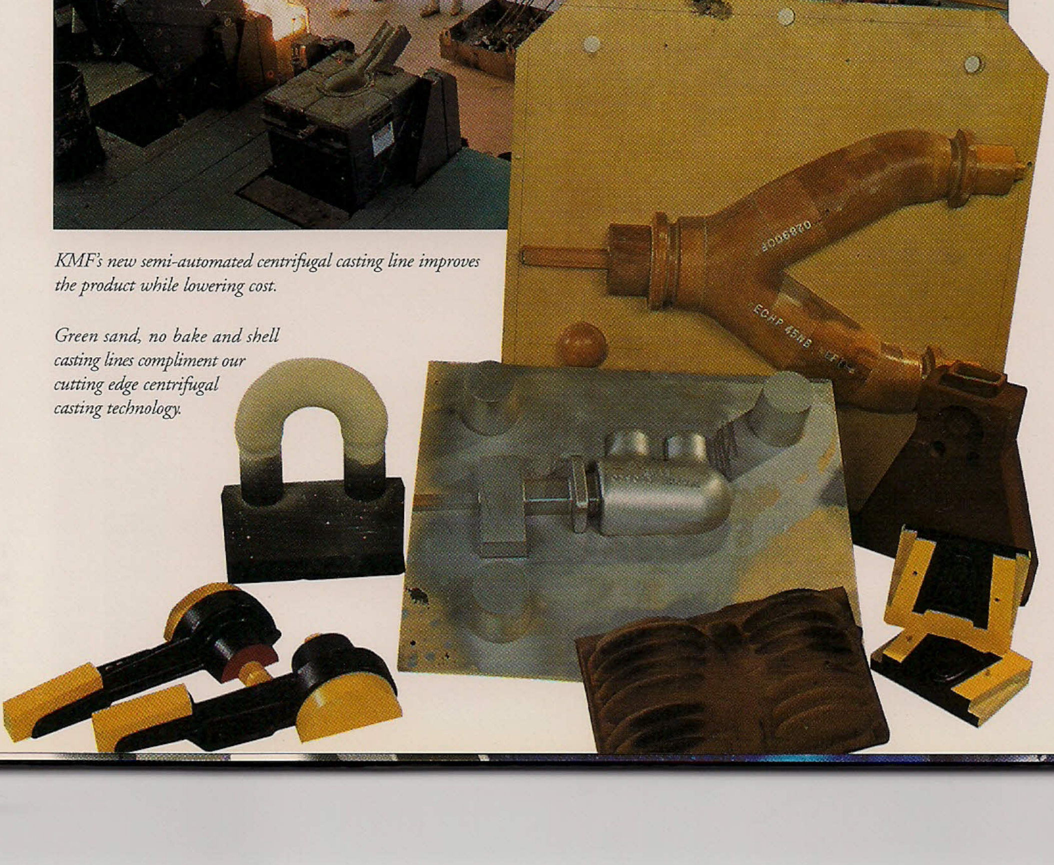
In general, oxidation resistance is enhanced by increasing the chromium and nickel content of the alloy, as is carburization resistance. Sulphidation is usually inhibited by high levels of chromium, and enhanced by high levels of nickel at low chromium levels.

Modifying elements also play a key role in corrosion resistance. Alloys containing niobium, for instance, can suffer severe oxidation damage under cyclic operating conditions at temperatures greater than 1950 °F (1066 °C) due to spalling of the normally protective oxide scale.

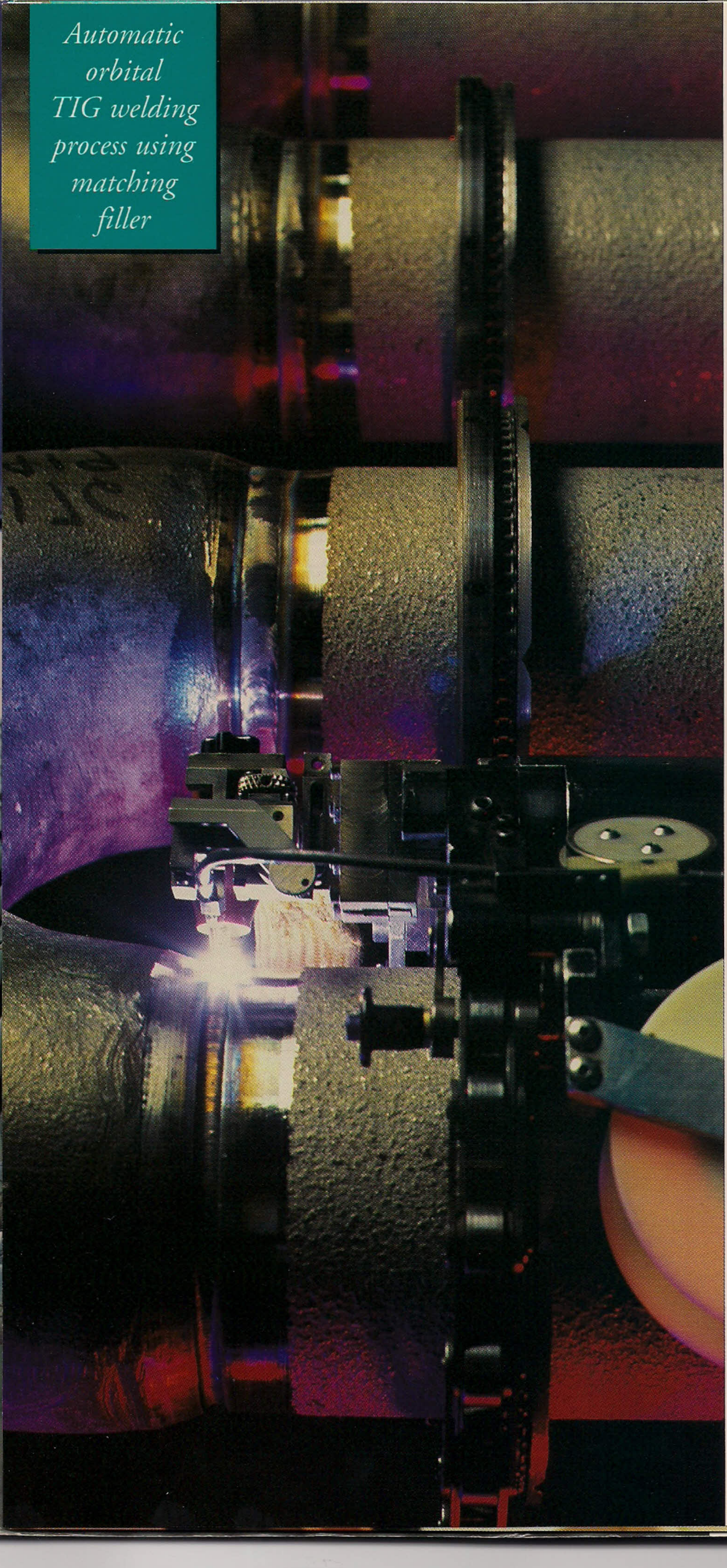
Carburization resistance can be slightly enhanced by additions of carbide forming elements such as tungsten, molybdenum, niobium and titanium, but is most significantly affected by the silicon content. Figure 6 shows the effect of increasing silicon on the carburization resistance of KHR35C. As mentioned previously, however, large silicon levels can be detrimental to strength, ductility and weldability, so the total silicon content must be chosen with care.



KMF's new semi-automated centrifugal casting line improves the product while lowering cost.



Green sand, no bake and shell casting lines compliment our cutting edge centrifugal casting technology.

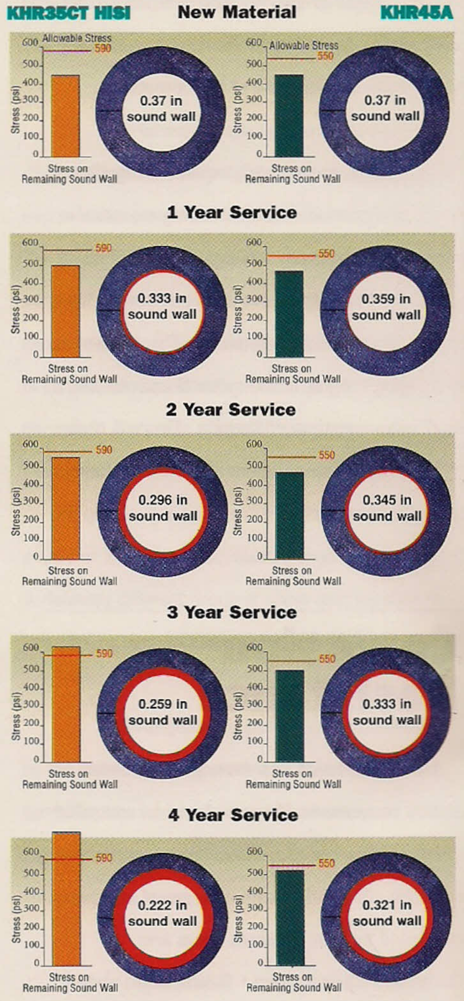


Automatic orbital TIG welding process using matching filler

Alloy Selection

It is very easy to choose the least expensive alloy alternative when purchasing a new component. Operators who take this option will often not realize the potential savings available from the use of stronger or more corrosion resistant materials. Alloys that exhibit greater corrosion resistance or greater strength than standard materials save money through reduced process downtime, reduced maintenance costs, and sometimes reduced capital cost. These types of cost savings are illustrated in the examples shown in Figures 7,8 and 9.

Figure 7 Cost savings through carburization resistance.



The graphic shows what happens over several years to two widely used alloys, operating under the initial conditions of 2000 °F, 100 psi, 4 in. I.D., and 0.370 in. wall thickness. After 2 1/2 years of service the effective wall thickness for KHR35CT HiSi has been reduced due to carburization to the point that the tube is operating at its 100,000 hr allowable stress, while this same stress is not reached until after 5 years of service for KHR45A.

Technical Support

Liquid penetrant application.

Several standard alloy choices have been shown for a typical reformer tube in Figure 9. HK40 is a standard alloy that has been in use since the 1950s. KHR20T is a microalloyed version of HK40 and represents a significant leap in strength. KHR35C and KHR35CT are non-microalloyed and microalloyed, niobium modified versions of ACI grade HP material.

Figure 9 shows that at 1650 °F (899 °C), alloy KHR20T provides the lowest cost product, but at 1750 °F (954°C), KHR35CT provides the lowest cost product. In both cases this cost reduction over HK40 material was possible because a thinner, and therefore lighter wall was enabled through the use of higher strength materials. Additionally, thinner walls improve heat transfer, increase the resistance to thermal cycling and allow a reduction in the weight of support components. Consequently fuel and maintenance costs are lowered and the reformer service life may be extended.

For ethylene pyrolysis service, resistance to carburization is as important as the strength of the material for the longevity of a furnace coil. KHR35CT HiSi and KHR45A are two materials for this service with similar high temperature rupture strength. However, KHR45A carburizes at about one third the rate of KHR35CT HiSi, according to Kubota laboratory tests.

Figure 7 illustrates how this difference in carburization affects the lifespan of a cracking tube. Assuming a carburization rate of 10% of the initial wall thickness per year for KHR35CT HiSi, after 2 1/2 years of service the effective wall thickness for KHR35CT HiSi has been reduced to the point that the tube is operating at its 100,000 hr allowable stress. This stress is not reached until over 5 years have elapsed for the KHR45A tube. Therefore, even though KHR35CT HiSi has a greater initial rupture strength, KHR45A tubes can be expected to last over twice as long under the same operating conditions.

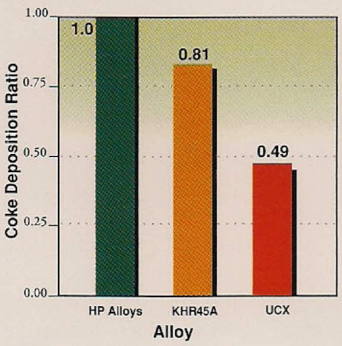
These are but two examples of how optimal alloy selection can reduce costs for our customers. The point is, the cheapest material does not always save you money.

Processes

KMF takes pride in its ability to manufacture complex, difficult and high quality castings and assemblies. Our centrifugal casting facilities include a state-of-the-art semi-automatic line for large volume orders. Our green sand, no-bake and shell foundry lines compliment our considerable capabilities in centrifugal casting.

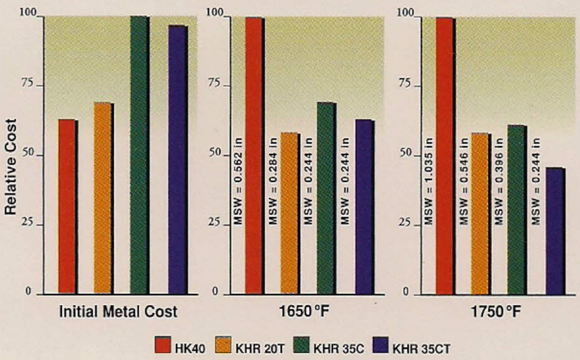
Heat treatment facilities and a full range of machining equipment prepare the product for final fabrication. Automatic, semi-automatic and manual TIG, MIG and stick welding completes the process. *KMF* provides automatic bed and orbital welds wherever possible, thus ensuring consistent, superior joining of components.

Figure 8 Alloy Coke Formation



Higher alloy materials such as KHR45A have shown a reduction in the tendency for coke formation in cracking tubes. The benefit to the operator is more production with lower operating costs.

Figure 9 Product cost comparison of various reformer tube alloys



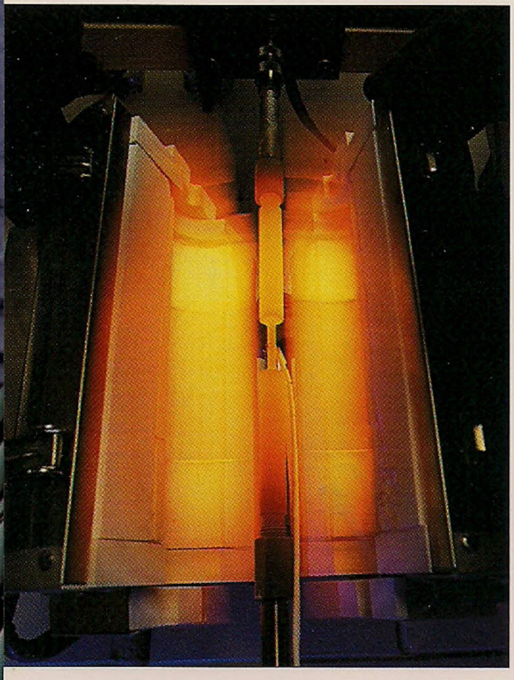
Using the formula for minimum sound wall thickness from American Petroleum Institute specification 530 a relative cost of a reformer tube was determined for 4 common alloys at 1650 °F (899 °C) and 1750 °F (954 °C). As is observed, KHR20T provides the lowest cost assembly for the lower design temperature, while KHR35CT provides the lowest cost assembly for the higher design temperature.

Kubota Carburization Detectors Created to help determine the amount of carburization in a cracking tube.

Quality Assurance

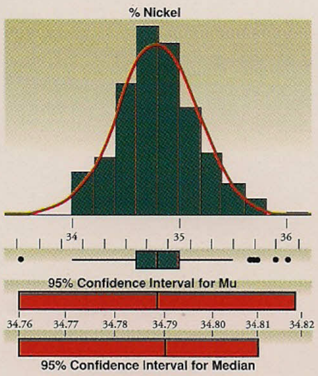
KMF Quality Assurance

Kubota's commitment to Quality Assurance is expressed through *KMF's* Quality Management System. This program maintains an environment of continuous product quality improvement in compliance with ISO 9002 standards. *KMF* was registered as meeting the requirements of ISO 9002 in 1995, making us one of the first companies in the industry to achieve this certification.



A 21 unit Creep-Rupture testing laboratory on site at KMF provides qualifying stress rupture (QSR) tests.

Figure 10 Descriptive Statistics



State-of-the-art analytical technology and statistical analysis ensure exceptional control of chemical composition.

KMF has full, in-house non-destructive testing capabilities for Liquid Penetrant Inspection (L.P.I.), Magnetic Particle Inspection (M.P.I.), Ultrasonic Testing (U.T.), Radiographic Testing (R.T.) and Pressure Testing (P.T.). For radiography, *KMF* utilizes the latest technology in gamma ray radiographic inspection. One hundred curie iridium and cobalt isotopes allow testing of sections up to 7" in thickness. All of these inspection methods help *KMF* to enforce a zero defect philosophy for petrochemical products.

Kubota's rigorous alloy composition requirements are enforced through the use of several analytical units. Our primary analytical instrument, a simultaneous x-ray fluorescence (XRF) spectrometer system, is supported by an arc/spark optical emission spectrometer system (OES), and by dedicated instruments for the analysis of carbon, sulphur, nitrogen and oxygen. These systems are integrated to allow *KMF* to maintain productivity when any of the other analytical instruments are taken off-line, thereby maintaining the same levels of accuracy and repeatability, while ensuring that production and quality are not compromized.

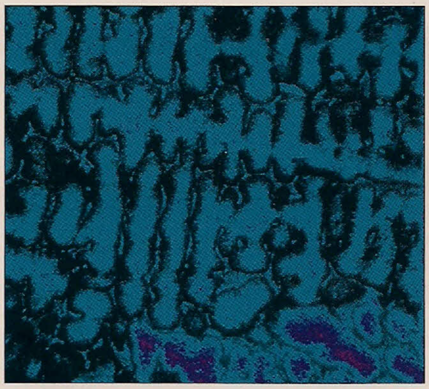
In addition to the chemical laboratory, *KMF* also has a state-of-the-art mechanical testing laboratory for physical property testing. Capabilities include a 60,000lb tension/compression testing machine, a 264 ft-lb capacity Charpy impact tester complete with a multi-cool cryostat for sub-zero testing, various instruments for Brinnel hardness testing, and a 21 unit creep-rupture laboratory.

KMF's state-of-the-art Statistical Process Control (SPC) technology makes a key contribution to quality by providing stringent control of manufacturing parameters and delivering uniform physical and mechanical properties. *KMF's* SPC program is unique in its focus on dendrite secondry arm spacing (DSAS) in centrifugally cast tubes.

It is the aim of Kubota Metal Corporation, Fahramet Division, to maintain an effective and efficient quality program capable of ensuring that conformance to specification and contract will be attained through the objective analysis of quality. Our dedication to quality is company-wide, and is backed by the necessary policies, procedures, and technology to produce products of the highest quality and diversity.

Technical Support

KMF is renowned for providing exceptional customer service and technical support, including in-house failure analysis, product research and development, and alloy recommendation. Research and development programs are supported by the Kubota Steel Castings Division R&D department, and also the Kubota Central R&D Division, comprising over 300 researchers. Kubota's unrivaled commitment to research enables us to better serve our customers today and in the future.



Dendrite Secondary Arm Spacing (DSAS)
Controlling tube microstructure provides the best control of the resulting physical properties.

The information in this brochure was accurate at the time of printing. For the most up to date alloy information please contact KMF for a copy of the latest revision of the alloy data sheet of interest.