TRENDS IN HEAT TREATMENT AND SURFACE ENGINEERING: A FEW EXAMPLES

P.Ramachandrarao
National Metallurgical Laboratory
Jamshedpur

INTRODUCTION

Heat treatment has been undergoing rapid changes in recent years. Many, if not all, of these changes are brought about due to the stringentrestrictions being placed by environmental considerations and increasing cost of power. Surface engineering on the other hand has been assuming steadily increasing importance by virtue of developments in other technologies such as generation of intense laser beams, production and control of widely different ion beams, greater resolutions in scanning probe microscopes etc. The present article attempts to illustrate the trends in these fields through a few examples. The cases discussed are only for illustrating a few of the many trends and are in no way exhaustive.

Furnace Technologies

Awareness of environmental problems and increasing cost of energy have greatly influenced the furnace designers and users. These have lead to the following:

a) development of better insulations;
b) changes in furnace configurations;
c) use of heat emanating from workpieces during cooling;
d) refining of exhaust gases for other applications;
e) in situ generation of carburising gas; and
f) control of NOx emissions.

Besides, the very need for certain heat treatment operations in achieving the desired result is being questioned. For example, the Japanese are now manufacturing many automotive forged parts without resorting to post-forging heat treatment.

Environmental pollution not only results from NOx emissions but also from chlorine-based organic solvents that are used for washing the components before and after quenching. To meet statutory controls, in several countries these are being replaced by hydrocarbons such as kerosene and hot water. Even flame treatment or use of burn-off furnaces are being attempted.

With a view to improve quality, reduce labour costs and human intervention, computer control is being used to manage increasingly large number of functions in the heat treatment shop. These range from workpiece tracking and delivery management to close control of furnace temperatures and atmospheres. Automation of batch furnaces, loading and unloading operations etc. are also becoming increasingly popular. It is expected that by the turn of the century, continuous processing technology will dominate over batch heat treating.

Another noticeable trend is a switch from electric heat treating furnaces to gas-fired units. This change over is expected to result in a reduction in operating costs and a better control on environmental pollution. In the USA, a programme initiated in 1986 has resulted in the development of gas-fired vacuum furnaces. The incorporation of a novel high convection heating arrangement has ensured far lower operating costs and more uniformity in temperature. Such furnaces are designed both for vertical and horizontal operations.

Gas Quenching

The ease with which cooling rate can be changed through the control of gas pressure and flow rate has been a great attraction for the use of gas quenching. This had particular attraction with respect to quenching of vacuum heat treated components. Over the last ten years our ability to handle high pressure gas at large rates of flow has improved significantly & today's furnaces use gases at 6 atm. with about an order of magnitude larger flow rates than about a decade ago. The heat transfer coefficients that are attainable have ensured that cooling rates attained are comparable to those in agitated oil baths. Three important factors contribute to the attainment of such large heat transfer coefficients. These are: the temperature difference between the load and the gas; the surface areas of the load; and the nature of the gas. Amongst the properties of gas that matter are its thermal conductivity, density, specific heat and viscosity. These are in turn controlled by the pressure and temperature of the gas. Table I gives the ranges of heat transfer coefficients that can be attained in gas quenching.

Table I : Heat Transfer Coefficients in Quenching

Medium and operating parameters	Heat transfer coefficient ($W.m^{-2}K^{-1}$)
Air, no forced flow	50-80
Nitrogen, 10 atm; fast	400-500
Helium, 10 atm, fast	550-600
Hydrogen, 10 atm, fast	~ 750
Helium, 20 atm, fast	900-1000
Hydrogen, 20 atm, fast	1300
Oil, 20-80°C, still	1000-1500
Oil, 20-80°C, agitated	1800-2200
Water, 15-25°C, agitated	3000-3500

The equipment for gas quenching may have a single chamber or multi-chambers. The latter are expensive and are better suited for large scale applications. Once again, more stringent laws for pollution control are driving heat treaters to opt for gas quenching. Considerable efforts are needed to bring in modelling to tackle the problems of distortion in gas quenching and design for the attainment of uniform temperatures with the aid of directed gas flows.

Plasma Processing

The stringent specifications of the aerospace industry have furthered the use of plasma technologies in heat treating. For example the plasma carburising process has several advantages over conventional atmospheric carburization:

i) faster accumulation and diffusion of carbon on the surface leading to 50% reduction in process times;

ii) higher hardenability potential resulting from higher surface carbon concentrations;
iii) greater uniformity in carburising of components with intricate geometry; and
iv) low energy consumption.

The major drawback of the process is the higher capital cost. The maintenance cost of plasma units is, however, lower than that of a vacuum carburising unit.

The possible mechanisms which lead to the injection of carbon into the surface of the workpiece are shown in Fig.1 (a) & (b).

The major reason for the faster absorption of C in plasma carburising is the greater absorption rate or C or C/H radicals than that of CO molecules.

Table II compares the carbon fluxes in plasma carburising with those attainable in low pressure carburising and gas carburising.

Table II: Measured Values of Carbon Flux for Different Carburising Process

Process	Type of gas	Temp. °C	Current density, i, mA/cm²	Carbon flux j, g/m²h
Plasma carburising	Propane-based	900	0.2	max. 100; av. 50
		950	0.2	max. 150; av. 70
	Methane	910	0.2	av. 20
			0.4	av. 45
	14% Methane	900	0.55	23
		940	0.55	32
			0.2	6
Low pressure carburising	Propane	910	—	approx. 60
Gas carburising	Carbon potential1.2%	950	—	max. 35

Both carbon potential and carbon flux have been proposed as a means of calculation and subsequent control of the plasma carburising process. Composition of the gas, gas flow, gas pressure, temperature and electric current density are the control parameters. For various reasons most of the variables pertaining to the gas and the temperature are kept constant or nearly so. As a result, the current density becomes the most important control parameter. The development of a plasma current density sensor by ISPEN has greatly helped control of the process. With adequate control, plasma carburising which produces no internal oxidation at or close to the surface leads to better wear and fatigue resistance. Hydrogen pick-up is either absent or is minimal. Simple masking methods for selective carburisation are an added attraction.

Besides the higher investment cost, the need to load components individually in baskets makes the process unsuitable for use with bulk items like screws, bolts, nuts, etc. Also, the surface in contact with the cathode does not get carburised. It is expected that plasma carburising as well as nitriding and other treatments will soon become popular and highly economical.

Beam Methods

Laser, electron and ion beams are playing an increasingly important role in surface engineering. The most powerful CO2 laser, till recently used exclusively for military purposes, has now been made available for commercial applications by the Wright-Patterson Air Force Base, USA. The laser produces a 17cm dia. beam and can deliver 150kW of continuous wave output power for 100s at a time. Such powerful lasers can allow us to undertake four distinct thermaland thermo-chemical treatments shown in Fig. 2.

These processes and their uses are:

(i) Transformation hardening: Solid state transformations such as the martensitic transformation can induce compressive stresses on the surface and help improve dynamic performance of components.

(ii) Surface remelting and freezing: When temperatures attained at and close to the irradiated surface exceed the melting point, thin layers of the component melt and solidify rapidly due to heat extraction through conduction. For example, a hard leduberitic layer with longer life expectancy can be formed on camshafts.

(iii) Surface Alloying: Combined with melting one can also induce alloying by introducing either another metal or hard particles of a second phase. One can then obtain additional hardness through alloying, dispersion and also grain size reduction through rapid solidification.

(iv) Cladding: Laser cladding enables the deposition of another material on the surface in a fashion that the deposited layer controls the surface properties.

Laser processing appears to have many advantages in comparison to flame and induction hardening or electron beam irradiation hardening as seen from Table III. Initial investment costs will outweigh the advantages only when the flexibility, reproducibility and ability for process control are also taken into account.

Table III: Advantages and disadvantages of various local surface hardening processes

* = Good + = Adequate - = Poor	Surface hardening process			
	Flame	Induction	Laser	Electronbeam
Spatial resolution	-	-	*	*
Accessibility	+	-	+	+
Intensity modulation	-	+	+	*
Low technical effort	*	*	+	-
Low investment costs	*	*	-	-
Flexibility	+	-	*	+
Low distortion	-	-	*	*
Self quenching	-	-	*	*
Quality of result	-	+	*	*
Surface oxidation	-	+	+	*
Single pieces	*	-	+	*
Complex geometry	+	-	*	*
Small pieces	-	+	*	*
Large production	-	*	*	*

Industrial value	+	*	*	*
Treatment of large components	*	*	+	-

The next most significant advances are taking place in the area of surface treatments through ion beams. Atleast three major areas can be identified. These are:

(i) Ion Implanation: In this method ions of a metal that is to be implanted are accelerated towards the target surface and get embedded upto 1μm depth. This leads to the formation of an alloy layer without significant changes in dimensions. Nitrogen, carbon, boron etc. can all be implanted. The process enables the production of alloys which are otherwise impossible to make. Limitations are the high operating temperature and small sample sizes.

(ii) Ion Mixing: In this case, a thin film of material to be implanted is deposited on the surface of the substrate and then mixed with it with the acid of an energetic ion beam. With an appropriate choice of film and substrate compositions and beam intensitie, it is possible to achieve even 90 at % concentration of the deposited element in the substrate upto depths of 1μm.

(iii) Ion Beam Assisted Deposition: In this we attempt simultaneous coating/bombardment resulting in the formation of thick dense and adherent coatings exhibiting well controlled structures and of desired compositions. Hard chromium coatings of 5-10μm are being produced on steel without the need for intermediate copper or nickel coatings. These coatings do not have hydrogen, are dense and have compressive stresses with little changes in dimensions. Even glasses, ceramics and plastics are amenable for such coatings.

Vapour Phase Processing

Using chemical vapour deposition, solid state diffusion and chemical reactions to great advantage Thermal Technology Inc. have come up with a novel process called High Temperature Vapour Phase Synthesis (HVS). In this technique (Fig. 3) the host metal in the derived form is heated in a high pressure enclosure and a reactive gas is then introduced. Reacted layer thickness can range from 3μm - 1 mm or more.

By this process one can form layers of carbides, nitrides, borides, silicides etc. or reactive metal such as hafnium, zirconium, titanium, tantalum etc. The products such as refractory metal crucibles have chemical stability and are not wetted by some liquid metals. These coatings are also abrasion and wear resistant. It is expected that HVS will become a much used technique for surface engineering.

MODELLING

We shall choose hardenability of a steel and its modelling as an example of the inroads made by mathematical modelling into the heat treater's domain. The importance of hardenability has further increased with the specifications becoming narrower and tighter. A new technique based on Jominy hardenability has been developed by British Steel Technical and UES Steels. The method is based on accumulation of measured Jominy hardenability and chemical composition in a random-access data file and its use for predicting the Jominy hardenability curve of a query steel. When the composition of the query steel is entered the software recalls ten steels whose composition is close to that of the steel under consideration and adjusts their hardenability curves to match the composition of the query steel. The final result is an average of hardenability adjusted from that of the ten steels. The adjustment for composition is based on a method developed by Field. Fig. 4 compares the measured hardenability with that obtained from the database results and the well-known methods of regression analysis for a 0.2%C - 0.8% Cr steel. The development of this hardenability prediction method has enabled both designers and steel producers alike.

Another example is the use of on-line monitoring and modelling for nitrocarburising. In a method developed by Brunner and Weissohn the composition of the furnace atmosphere is monitoried and measured by an optical system and a zirconia solid electrolyte sensor. The data is used to calculate the phase diagram and indicate the operating point. The display (Fig. 5) also shows the tendency to form carbides, compound-layer and pores.

CONCLUSIONS

Rapid strides are being made in adapting the heat treatment methodologies and procedures to the ever increase demands on energy saving, pollution control and stringent specifications. Increasing use of sensors, controls and computers will progressively reduce human intervention in heat treating and also make heat treatment a continuous process. Greater use of plasma and ion beam methods of surface engineering will pose challenges to the well established methods of surface hardening. Heat treaters will increasingly depend on mathematical modelling in the design and control of the heat treatment process to meet the narrowing specifications. It is hoped that the few examples cited above give a flavour of the impending changes.

BIBLIOGRAPHY

1. Banno,J; Heat Treatment of Metals, 1994.1, pp.21-26.
2. Billingham,R; Heat Treatment of Metals, 1992.4, pp.97-102
3. Sikirica,S.J.; Hemsath,K.H.; Panahi,S.K.; Heat Treatment of Metals, 1993.2, pp.35-38
4. Conybear,J.G.; Advanced Materials & Processes, 2 (93); pp.20-21
5. Edenhofr,B; Conybear,J.G.; Legge,G.T.; Heat Treatment of Metals, 1991.1, pp. 6-12
6. Girdwood,W.J.; Advanced Materials & Processes, 1(93), pp. 25-26
7. Hick,A.J.(Ed.); Heat Treatment of Metals, 1993.3; pp. 77-88
8. Holtkamp,B.; Advanced Materials & Processes; 12(93) pp. 45-47
9. Deutchman,A.H.; Advanced Materials & Processes, 1(93); pp. 22
10. Billings,G.W.; Advanced Materials & Processes, 4(93); pp. 45-46
11. Geary,E.A.; Cook,W.T.; Lane,K.A.G; Heat Treatment of Metals, 1993.4; pp. 95-98

FIGURE CAPTIONS

Fig.1(a)	Suggested mechanisms for carbon diffusion (Rembges)
Fig.1(b)	Mechanism suggested by Edenhofer et al
Fig.2	Various possible treatments of the surface with the aid of lasers (A.J.Hick)
Fig.3	Equipment for high temperature vapour-phase synthesis (G.W.Billings)
Fig.4	A comparison of hardenabilities calculated from the Database with those obtained by regression analysis and measurement (E.A.Geary et al)
Fig.5	Control of nitrocarburising process (A.J.Hick)

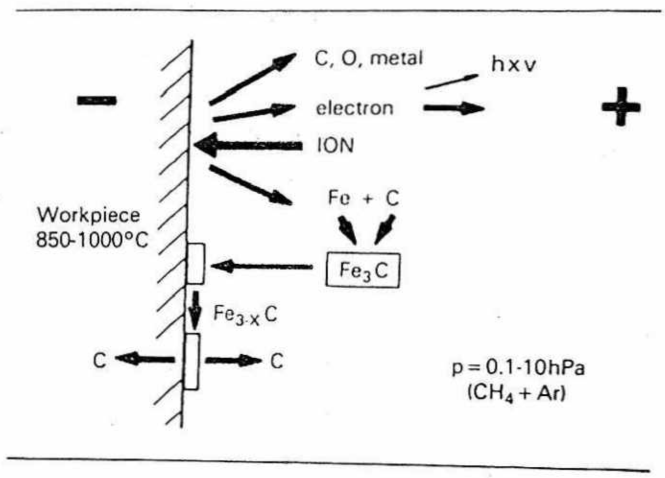

Fig.1(a): Suggested mechanisms for carbon diffusion(Rembges)

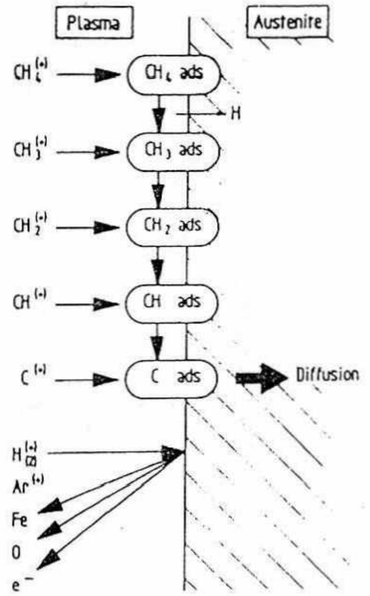

Fig.1(b): Mechanism suggested by Edenhofer et al.

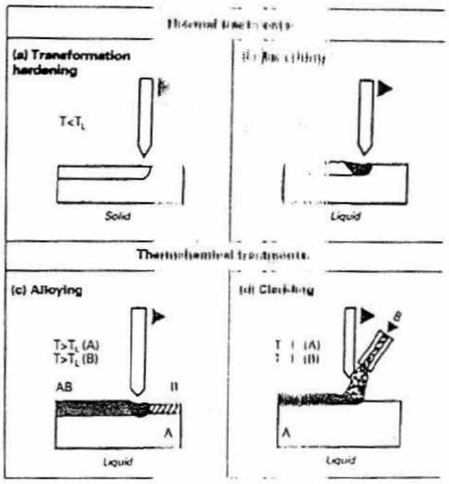

Fig.2: Various possible treatments of the surface with the aid of lasers (A.J.Hick)

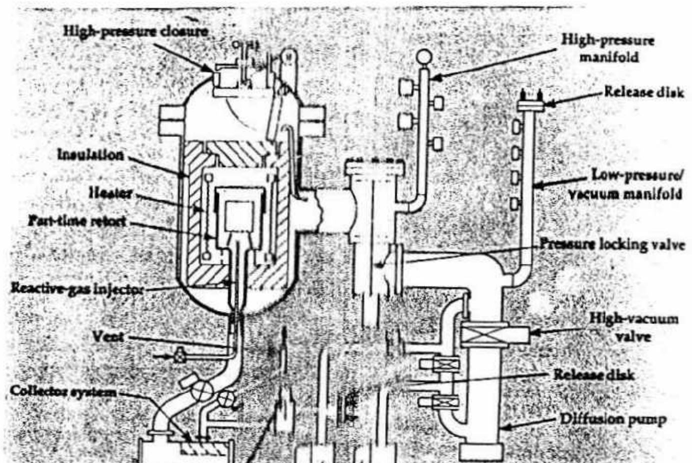

Fig.3: Equipment for high temperature vapour-phase synthesis.

(G.W. Billings)

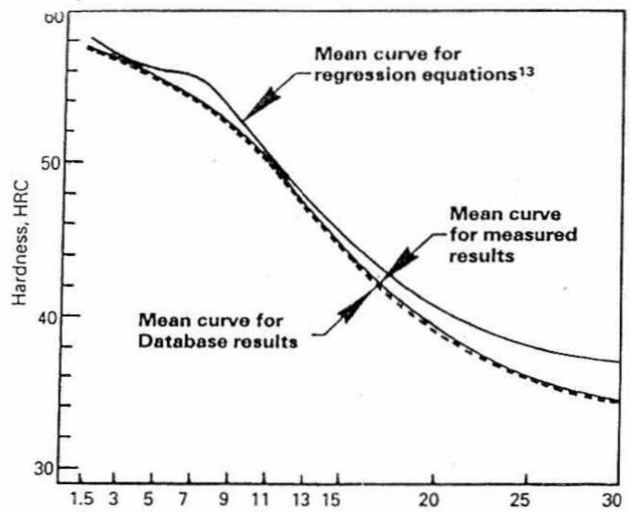

Fig.4 : A comparison of hardenabilities calculated from the Database with those obtained by regression analysis and measurement (**E.A. Geary et al**)

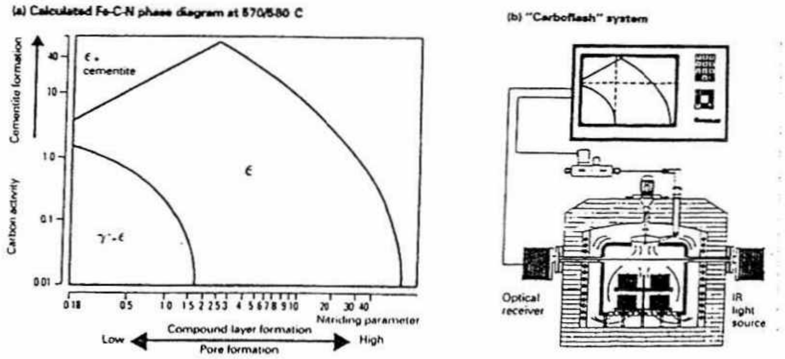

Fig.5: Control of nitrocarburising process
(A.J. Hick)