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OVERVIEW

HEAT TREATMENT OF AUTOMOTIVE COMPONENTS: CURRENT STATUS AND FUTURE TRENDS

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ABSTRACT

An automobile is composed of various material components which are produced by utilizing a wide variety of technologies and which satisfy customer needs and environmental norms. Heat treatment and surface modification are the key technologies available today, to enhance the effective use of materials, to achieve the desired properties of the components used in the automotive industries, to save energy and conserve natural resources. A short overview of automotive materials is presented in this paper. Selected aspects of heat treatment and surface modification technologies including future technological possibilities, of relevance to the automotive industry are also reviewed.

1. INTRODUCTION

The automobile is a typical industrial product that involves a variety of materials and technologies. The present societal needs necessitate that vehicle weight reduction be achieved through the use of relatively lighter materials. However, in spite of the increased use of aluminum and plastics, iron and steel content of a modern vehicle continues to be as high as 70%. Metallic materials are ideally suited for applications in heavily stressed components that require high durability. The degree of functionality and component performance is strongly tied to the effectiveness of the processing technology deployed for a given application.

Body parts are usually produced from steel sheets that have been rolled and thermally processed to create the desired properties. The heavier body part components are manufactured through a process traditionally characterized by stamping, welding and coating leading up to the assembly process.

Automotive gears represent another important category of components that are heavily stressed and require high levels of performance in the areas of both fatigue and wear resistance. Effective and appropriate heat treatment and surface modification technologies are utilized to optimize properties of virtually all types of metallic components with durability featuring prominently in a great number of applications.

Beginning with raw metal products leading all the way to final component assembly, various types of heat treatment and surface engineering processes are applied in the manufacture of automotive components. Heat treatment processes impart the required strength or hardness properties as dictated by the given component application. Other processes involved in metal processing may include forming, machining as well as quench and tempering, carburizing and hardening and nitriding during production. Surface modification, when properly applied, yields optimum surface properties enhancing corrosion and wear resistance while improving frictional properties.

2. MATERIALS USED IN AUTOVEHICLES

In spite of tremendous efforts being made to develop vehicles made of all aluminum auto body, most automobiles today are composed of iron and steel (70%), aluminum (6%), plastics (9%), rubber (4%), glasses (3%) and miscellaneous other materials (8%). To fulfill the fuel economy targets, it is necessary to reduce vehicle body weight while also improving engine and rolling energy losses. These improvements are being achieved through the use of high strength steel sheets and/or in conjunction with even greater increased usage of aluminum, magnesium and titanium alloys having lower specific weights compared with iron and steels [1].

As shown in Table 1 the possibility of weight reduction via the use of ultra high tensile strength sheet steels has been achieved. These ultra-high-tensile strength steel sheets are produced using advanced steel mill technologies characterized by controlled rolling and cooling technologies and heat treatment.

Challenges in body design and fabrication technology to optimize weight savings have been studied as a world wide development program as Ultra Light All Steel Body–ULSAB- as shown in Table 2 [2]. Weight reduction through the use of other materials is illustrated in Table 3. Some of the current trends in used materials for automotive applications are briefly summarized in the section and in Tables 4,5 and 6.

2.1 Bake Hardening Steel Sheets

Low yield strength and good formability steel sheets are necessary for stamping and forming operations. However, body panels need stiffness and strength to increase crash worthiness and fatigue resistance. Both of these needs at first were fulfilled by bake hardening steel sheets. These type of sheets are formable during stamping operation, but hardened by baking after painting. The baking condition can improve strength level from less than 30 kg/mm^2 to about 45 kg/mm^2. This technology contributed greatly to the improvement of productivity and body strength and durability of vehicle body, simultaneously enabled the production of high fuel mileage vehicles, and additionally contributed to the improvement in crash worthiness.

2.2 High Tensile Strength Steel Sheets

Strength of sheet steels are improved by optimization of chemical composition and rolling and cooling technologies.

Further increase of high tensile strength sheet (Hiten) usage seems necessary to strengthen body shell while reduce its weight to accomplish fuel mileage targets. Various investigation and development efforts have been devoted as reported in the Ultra Light Steel Auto Body – ULSAB-, and ULSAB-AVC- Advance Vehicle Concept [2,3].

2.3 Corrosion Resistant Coated Steel Sheets [4,5]

Body panel sheets are to be coated to prevent perforation caused by salt splash during winter. Various types of coating such as zinc dip coating, Zn-Fe alloy coating, Zn-Fe plating and Ni-Zn plating

Table 1

PAST TRENDS IN WEIGHT AND MATERIALS OF A TYPICAL PASSENGER CAR

Model* year	Weight (Kg)	Total Iron & steels	Sheet steels	Construct steels	Cast Iron	Non Ferrous	Plastics	Rubbers	Glasses, & Ceramics	Mis-celleneous Materials
1968	1020	75.0	46.9	14.3	13.8	6.0	3.6	3.6	3.0	7.4
1978	1144	75.7	44.1	20.2	11.4	7.8	5.0	5.0	2.4	3.4
1988	1300	73.7	42.5	20.8	10.4	7.2	7.1	7.1	2.6	5.4
1992	1290	71.7	37.5	23.9	10.3	9.2	7.5	7.5	3.1	4.3
1996	1313	69.8	35.5	23.7	10.2	10.4	9.2	9.2	2.9	3.6
2000	1371	68.7	36.6	23.9	8.2	10.6	9.0	9.0	2.6	4.1
2000 / 1978	1.198	0.908	0.830	1.183	0.719	1.1359	1.1359	0.911	1.083	1.206

*Vehicle model Toyota Mark II

Table 2
STEEL SHEETS USED IN ULSAB-AVC. [3]

Tensile Strength (MPa)	Designation Type- Y.S./ T.S.	Yield Strength (MPa)	Type of High Strength	(%)
~ 450	Misc.	- - - - -		2.31
	BH 210/340	210	Bake Hard.	3.98
	BH 260/370	260	Bake Hard.	5.82
	IF 300/420	300	Interst. Free	4.18
	HSLA 350/450	350	HSLA	1.23
500 ~ 600	DP 280/600	280	Dual Phase	6.89
	DP 300/500	300	Dual Phase	7.98
	DP 350/600	350	Dual Phase	2.76
700 ~ 800	DP 400/700	400	Dual Phase	4.18
	TRIP 450/800	450	TRIP	4.09
	DP 500/800	500	Dual Phase	22.56
	CP 700/800	700	C Precipitate	0.52
1000	DP 700/1000	1000	Dual Phase	30.02
1200 ~ 1500	Mart 950/1200	950	Martensite	2.67
	Mart 1250/1520	1250	Martensite	0.81

Y.S:Yield Strength, T.S: Tensile Strength, Bake Hard: Bake Hardening. Interst. Free: Interstitial Free. HSLA: High Strength Low Alloy. C Precipitate: Precipitation Hardening.

Table 3
EXAMPLES TO IMPROVE FUEL MILEAGE THROUGH ENHANCED USE OF HIGH TENSILE STRENGTH STEELS OR ALUMINUM ALLOYS. [1]

Vehicle	Iron & steels (wt %)	Al-alloys (wt %)	Mg-alloys (wt %)	Plastics (wt %)	Rubber (wt %)	Glasses (wt %)	Misc'l mat'ls (wt %)	Weight (kg)	Fuel mileage (km/l)
Base (1950)	70	6	-	9	4	3	9	1040	14.6
Case A: (+ Hiten)	61	12	1	11	4	3	8	915	15.8(+12 %)
Case B: (+ Al alloys)	31	34	4	14	4	4	9	780	17.0(+25 %)

Fuel mileage: (10-15 modes), Case A: More use of High tensile strength sheets, Case B: More use of Aluminum alloys.

Table 4
MATERIALS USED FOR CRANKSHAFTS [6]

Materials	Heat treatment	Pin & journal
DCI: FCD700	Annealing	SB Nitriding
S48 ~ 55CL	Quench and temper	Fillet rolling
SCM435,440 S40 ~ 45CV-(L)1040,45 + V,L	Quench and temper Forge and direct control cooling-DHT	Induction hardening Fillet Rolling
SCM 415	Isothermal annealing	Carburizing

DCI: Ductile Cast Iron, SCM-xx: SAE-41xx, DHT: Direct Heat Treatment.

Table 5
MATERIALS USED FOR CONNECTING RODS [6]

MaterialsSpecific.	H.T and S.M.	Hardness HB	T.S. MPa	Y.M. GPa	S.W gr/cm^3
S48 ~ 55C 1048 ~ 55	Quench & Temper	260	900	206	7.8
SCM 435 ~ 440	Quench & Temper	300	1000	206	7.8
S43CV(L)1043 + V,L	Quench & Temper	260	900	206	7.8
SMF 4030 (P.M.)	Sinter-forge & Q.T	260	900	206	7.3
Ti-3Al-2V	Forge, refine& CVD-TiN	240	800	113	4.4

SCM435, 440: SAE 4144

Table 6
AUTOMOBILE COMPONENTS MADE OF MAGNESIUM ALLOYS

Company Name	Components
Mazda	Transmission case, Clutch housing,Engine front cover, Oil pan. Etc
Toyota	Steering column upper brackets, Steering wheel cores, Brake pedal brackets, Cylinder head cover, Disc wheel, Instrument window frame & etc
North America & Europe	Clutch housing, Manual Transmission case, Steering column bracket, Cylinder head cover, Intake manifold, Accessory drive brackets, Instrument panel frames, Wheels, brake and clutch pedal brackets, Seat frame, Oil filter adapters, EGR valve covers, A/T stators, and pistons, Decorative nameplates, Window motor housings, Radio housing & covers, Mirror brackets, Head light retainers and etc.

are used for panels. Also Al coating and Al-Zn coating are used for exhaust line pipes and mufflers similar to some types of stainless sheet and pipes.

Fuel tank also needs corrosion resistant coating like lead, but is no longer applicable to reduce hazardous scraps. [4]

2.4 Constructional Steels

Various types of construction steels are used to fabricate high performance components in engines, suspensions and power train components that need strength and durability. Strength of components is introduced by the selection of appropriate steel grade and appropriate heat treatment to give necessary strength and fatigue durability. While the weight cut is necessary to improve fuel mileage, steel components have to maintain strength and additionally, various types of fasteners and screws used to assemble body, transmission, chassis components and auxiliary parts are made of steels. However, a gradual transition toward conversion to lighter fastening mechanism will proceed further. The competition with such material transition may necessitate the development of the more effective component design with durability by effective use of the structural steel products with optimum heat treatment.

2.5 Case Hardening Steels

Case hardening operations are quite important to introduce hardness, static and dynamic strength with wear and seizure properties. Because the properties of simple quench and hardened steel are not sufficient to withstand bending, and rotating stress and friction, varieties of surface hardening processes are applied to produce automotive components. Case hardness is increased by diffusion of carbon and or nitrogen and quench hardening processes such as carburizing, nitriding and induction hardening etc. Various grades of case hardening steels are used for the production of automotive components such as transmission gears and shafts.

2.6 Heat Resistant Steels

Engine valves, especially the exhaust valves require high temperature strength and are made of heat resistant steels. However, the necessary high temperature strength of shaft area and valve seat portion is quite different. Therefore, two different grades of heat resistant steels are joined together to fabricate valves. Additionally, nitriding has been applied to valves to improve wear and seizure properties.

The valve seat portion of high performance engines requires high temperature wear resistance during high temperature operation and Stellite-alloy deposition on seat contact portion is popular by high energy cladding methods such as Inert Gas-Arc or, Laser alloying processes. [7]

Heat resistant alloys are also used for exhaust turbine rotors for high performance turbo-charged engines. These components are made by investment casting methods; however some of them are now made of advanced ceramics such as Silicon Nitride.[8]

2.7 Powder Metallurgy Products

Powder compaction and sintering technologies are widely applied for production of engine and transmission components. They are mostly Iron base and Copper base alloys. Titanium alloys are used for certain limited applications.

Iron base powder alloy parts that are being manufactured include:

- Crank timing sprockets or gears
- Cam shaft timing sprocket or gears
- Transmission clutch hubs
- Powder forged connecting rods
- ATM planetary ring gear
- Cam robe of Composite Cam shaft
- Door lock strikers etc.

Non-ferrous alloy powder metallurgy products

- Plane bearings Cu-Pb
- Plane bearings Al-Sn
- Valve seat inserts
- Exhaust valves Ti-TiB_2

2.8 Copper Alloys

Bearing materials are necessary to fabricate plane bearings for engine crankshaft and connecting rods. Copper alloy has been the main material for plane bearings, but usage of aluminum alloys is steadily increasing.

Electric wire products such as wire and thin ribbon wiring or cables are made up of Copper alloys. Valve seats use Cu-base alloys to optimize wear properties.

The new trend toward the use of Hybrid, Fuel Cell with electric motor power drive train will increase the use of conductive materials in the coming future. However, new research and development studies are needed to reduce the specific weight of Copper and Magnetic materials. These studies are aimed at in the overall reduction of components weight.

2.9 Aluminum Alloys

Typical products made of aluminum alloys include cases for transmission, differential and steering gear boxes. In order to reduce the weight of the vehicle, aluminium sheets are being used for panels such as engine hood, trunk rid cover, body panels and suspension components. [9] Bake hardening technology used for steel sheets was applied to develop new aluminum alloy applicable to body panels (Fig. 1)[10].

2.10 Magnesium Alloys

The light magnesium is very attractive to reduce components weight, but stiffness, strength and corrosion properties are poor to increase application in vehicles. However, Mg alloy had been used for old Volkswagen since 1950's utilizing lightest metal property. Thought the Mg alloys are expensive their utilisation is marked by high weight / strength ratio. Particularly, corrosion resistance of Mg alloys available in the market are not sufficient to satisfy application needs, and hence low impurity alloy grade has been developed for automotive applications. [11]

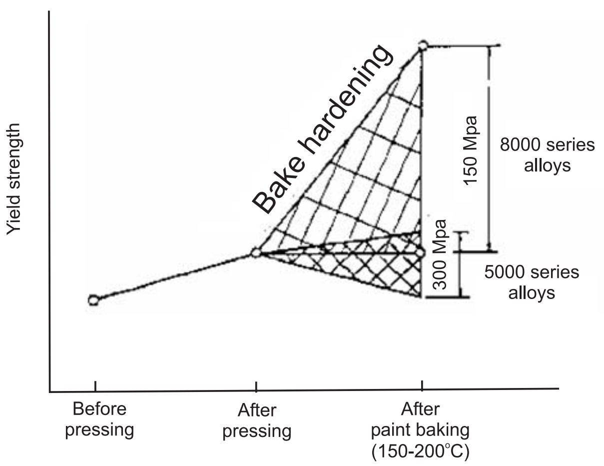

Fig. 1 : Change of Yield Strength by paint baking (Courtesty Sumitomo L.M.I.)

2.11 Titanium Alloys

Titanium alloys have excellent specific rate - weight/ strength ratio- but the high cost of materials is the biggest hindrance to the expansion of titanium applications in automotive industry. Candidate components fit for Ti alloy use include valve spring retainers, [12] suspension coil springs [12] and connecting rods [13].

The biggest hurdle to titanium alloy usage was solved by the development of new production methods via the use of powder metallurgy processes. Toyota developed a low cost process starting with sponge titanium powder to fabricate valves. These valves are found cheaper than heat resistant steel valves. Figure 2 shows the main production steps that enabled the mass production of light-weight titanium valves for passenger car.[14]

2.12 Composite Materials

Soft and weak materials can be strengthened by reinforcement of fibers or particles. Glass fiber reinforced plastics are used for roof panels and many other plastic products. Metal Matrix Composites are not popular in automotive industry but these materials are useful to increase local strength where components need stiffness or creep strength.

Toyota has been using Composite Engine pistons since 1981 [15]. This Diesel engine piston has been produced by the successful development of quite simple Alumina-Silica fibers that were squeeze- cast into the top portion of Al alloy piston. Since 1981 various technical improvements have been made and recent MMC piston is reinforced by porous Nickel preform around the ring groove. [16-18]

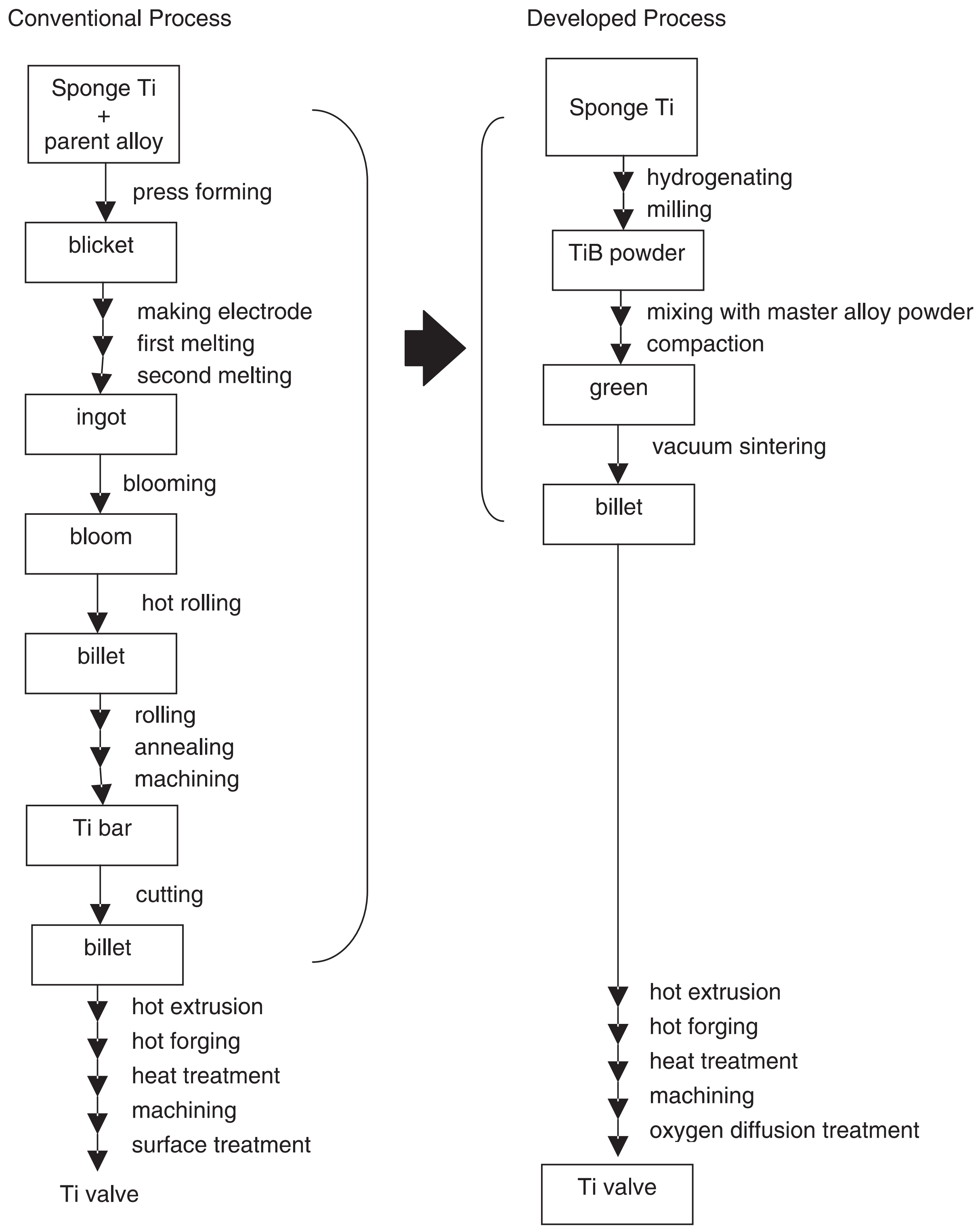

Fig. 2 : Flow Charts for the valve making process (Courtesty Toyota Motor)

Following components are made of MMC in vehicles: diesel engine pistons (Fig. 3) [9, 15-18], engine cylinder block bore portion [19], crank dumper pulley shaft hole [20], and connecting rod [21].

2.13 Plastics and Rubber

The share of plastics usage in the auto body has been steadily increasing. Main target is to develop plastic materials that are environment friendly and can be recycled to reduce wastes. Plastic panels are competing with Aluminum and high strength steel sheets. The usage of plastics for fasteners, connectors and covers are increasing steadily. Although used weight or volume is small, plastics and resins are used for metal-laminate products such as noise dumping sheet and light weighted laminate steel sheets having specific strength comparable to aluminum alloys.

Rubber has been used commonly as tires and sealing weather strips. While rubber may stay as the basic material for tires, but many rubber applications such as seals and weather strips is meeting competition with new grade of plastics.

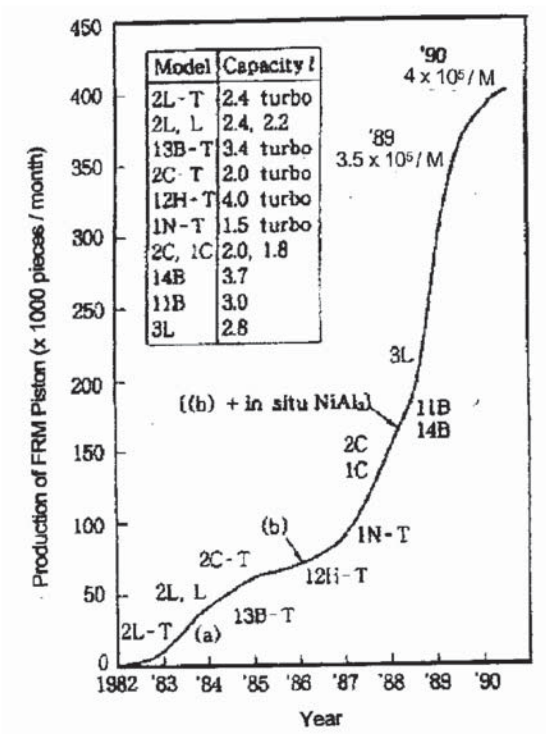

Fig. 3 : Production of FRM Piston (Courtesy Toyota Motor)

2.14 Glass and Ceramics

Glasses are used for windows and covers for lighting, while windows seems to stay as the base application, but housing and covers of lights are being replaced by translucent plastics. Ceramics are finding numerous applications from traditional spark plugs to components such as oxygen sensors, catalytic converter and advanced ceramics such as turbo-charger rotor, exhaust valve and valve lifter shims. Diesel particular filters and PZT actuators and many other ceramic products seem gradually increase their applications related with increased use of electronics components.

3. HEAT TREATMENT

3.1 Types of heat treatment

Selection of steel types and grades and appropriate heat treatment methods are very important to produce components of reliable quality. The control of a given alloy's chemical composition and the inclusion content of steel have an impact upon and can create variance in an alloy's properties. Other contributing factors impacting the quality and reliability of final components include refining, casting, rolling and cooling methods. Further, strength, toughness, fatigue strength and wear properties result largely from the microstructure and hardness results created by heat treatment condition and methods applied. As a result, it is quite important to be cognizant of these factors and to ensure that appropriate methods are applied.

Types of heat treatment used for production of automotive components are listed in Table 7.

3.2 Processing technology in heat treatment

Since the advent of gas carburizing processing, various improvements in furnace, atmosphere and their control methods have been achieved and hundreds of continuous heat treatment furnaces are utilized in the production of automotive vehicles. Improvements in furnace design have enabled considerable savings in energy to be achieved. Also considerable improvements have occurred in moving toward the application of reduced pressure controlled processing methods. Vacuum carburizing and nitriding methods are gradually increasing in usage and plasma assisted technologies have further advanced the capabilities of these processes.

Table 7

TYPES OF HEAT TREATMENT AND SURFACE HARDENING USED FOR PRODUCTION OF AUTOMOTIVE COMPONENTS.

Types of heat treatment	Purpose	Typical components
Annealing	Softening, and removing residual stress for post processes	Forged blanks for gearing and misc. parts
Isothermal annealing	Transformation control hardness and micro-structure for machining.	Machinability control
Normalizing	Control microstructure and hardness for machining	Reduce hardness for machining
Spheroidizing	Control microstructure and hardness for cold forming	Reduce hardness and microstructure for cold forming
Control roll and control cooling	Control rolling and control cool for bake hardening and high strength steel sheets.	Body panels and frame [2,3] Joint yorks, Crank shafts, con' rods,
Forge and direct cooling	Forge and directly quench or control cool.	Steel sheet panels. [4]
Quench and temper	Optimize hardness for strength and toughness	Fasteners, Rods and Arms
Austemper	Optimize microstructure and hardness via isothermal transformation	Cast iron brackets, High carbon springs
Solution treatment and aging	Optimize hardness and strength of Al and age hardening metallic materials.	Aluminum casting: (T/M & Dif. casings In. & Ex. Valves
Case hardening: (Pack, Salt bath, Gas, Vacuum, Plasma) Carburizing Carbonitriding	For fatigue strength and wear resistance through diffusion of Carbon and or Nitrogen at the surface of components and quench for case hardening	For fatigue and wear resistanceGears and shafts, Same to above carbon steels
Oxidizing Nitrocarb-oxidizing	Oxidize surface to improve corrosion, wear and scuff resistance. Steel Titanium	Corrosion and wear resistant of steel and Ti alloys
Induction hardening	Heat up by inductive power and quench to get hard case locally.	Cam shafts, Drive shafts, steering knuckles
Induction tempering	Heat up by inductive power and slow cool to soften heated area	Thread area of shafts
Nitriding: (Salt, Gas, Vacuum, Plasma) Nitro-carburizing Oxy-nitro-carburizing	Diffuse Nitrogen, C and or O depending to impart wear and corrosion resistant nitride layer at surface and to get a deeper diffusion layer to improve fatigue strength	Cam shafts, oil pump gears, valves, Brake pad liner plates, A/T gears
Diffusion coating (Salt bath, Gas)	Diffuse Cr to form chromium film, carbide and etc.	Chain pin, stove pipes, Forming Dies
Remelt refining (Laser, TIG etc)	Heat and melt surface and solidify quick to get fine crystal structure	Cam nose and valve seat wall
Alloying (TIG, MIG, Laser, EB)	Melt and mix with added powder materials to improve surface properties	Cam profile, Valve seat of cylinder head and valves
Powder metallurgy	Compact and sinter metallic powders to get desired composition and shape	Engine sprockets, gears, T/M sliding hubs
Thermal spray coating (Plasma, TIG, MIG)	Spray molten particle to get desired composition for wear resistance, etc	Piston ring, Lifter periphery, Synchronizer ring
Post treatment processes: Coat forming quench Cryogenic treatment Shot peening (0.8 ~ 1.4 C steel or cast iron shot) Hard, double peening Fine particle peening (Fine particles)	Improve surface properties Form protective film during quenching	Fasteners, V.S. retainer
	Deep cooling to end transformation	Dies, Gears
	Spray particles to clean or increase residual stress and fatigue strength	Leaf and coil Springs
	Spray hard large and small particles to increase residual stress for higher fatigue strength.	T/M and differential gears
	Spray fine particles to clean, remove thin surface layer and to form shot dimples	Piston skirts, Continuously Variable Transmission drums

Components made of steels are usually forged and, then quenched and tempered or isothermally annealed, machined and case hardened to give required strength, durability and fatigue life to automotive components. However, these heat treatment processes involving repeated heating and cooling consume large amounts of thermal energy. Since 60's, forge and quench methods have been applied to utilize energy conservation by elimination of reheating operations. This method was first applied to plain carbon steel to increase quench hardenability by appropriate thermo-mechanical treatment.

Micro-alloyed steels enable the application of direct heat treatment after forging. Similarly control cooling technology facilitated the production of high strength steel sheets. Forge and direct quench or direct control cool methods enabled the elimination of post heat treatment and contributed to great reduction in consumption of thermal energy. The forge quench method can reduce nearly eighty percent reduction of thermal energy compared with traditional heat treatment processes which needed repeat heating and cooling. It is a very energy efficient heat treatment process applicable to hot forged blanks and components. The thermal energy of forged components is fully utilized to create the desired microstructure through the deigned controlled cooling methods such as air blasting, water spray cooling or quenching. The alloys processed through these routes typically yield the same strength levels as compared to traditionally quenched and tempered products. [6]

Austempering processes are applied for cast products to yield high strength and ductility. The strength of austempered cast iron is comparable to the standard quench and tempered steels and finding application in suspension and brackets.

3.3 Carburizing and Carbonitriding

Carburizing is the most popular case hardening method widely used for automotive gears. The carburizing process diffuses carbon into the surface of heat-treated components in an atmosphere controlled [22] furnace followed by directly quenching the processed gears into a selected quenchant thus introducing high carbon quenched, hard martensite case. Conversely, carbonitriding diffuses carbon and nitrogen simultaneously [23].

3.4 Nitro-carburizing

Salt bath nitrocarburizing processes have made a great contribution to the improvement in components durability by improving wear and fatigue properties. Since the process used cyanide the environmental issue affected their usage. As a result several other gas nitrocarburizing methods have been developed and their applications expanded. [24]

Low temperature nitriding, nitrocarburizing and oxy-nitrocarburizing are becoming more popular due to the benefits their heat treatment temperatures hold in preventing thermal and transformation related distortion. The iron nitride layer at the surface gives excellent wear and seizure resistance and nitrogen diffused into the component's sub-surface area increases fatigue resistance by quenching to prevent precipitation of iron nitride while containing nitrogen within the ferrite matrix. [25]

3.5 Induction hardening

It is widely applied to automotive components that require locally hardened areas. Cam shafts, ball joint stud and miscellaneous components are induction hardened to yield high surface hardness by induction heating and quenching. Induction heating is also an energy efficient heat treatment process not only for hardening while also having the benefit of being able to soften selected area for improvement of toughness in case hardened components. Recent technology enabled hardening of gear tooth profile via the precise control of heating cycle and optimum coil design.This profile hardening process can introduce extraordinary high compressive residual stress at the surface layer compared with traditional carburizing and hardening processes. The combination of technologies to optimize case depth with the high residual compressive stresses seems to expand their application into gearing of transmission and machines. [25]

3.6 Powder Metallurgy and Sintering

Powder compaction and sintering process are finding wider applications. Transmission and engine components such as clutch hub, timing sprockets and gears are typical examples made of iron powder. The powder processing technologies are advancing further to introduce more powder metallurgy products. [25]. Valve seats in cylinder head are excellent example of powder products that enabled the introduction of specially designed valve seat materials necessary to fit with severe engine operating condition. [26]

Powder forged connecting rods were developed and used in BMW Engines [27]. Toyota also developed powder forged connecting rods in engines [28]. Variable valve timing gears used for Engine are also made from iron based powder alloy [29]. The most advanced powder metallurgical application is in the manufacturing of Titanium valve produced via compaction, sintering, extrusion, and swaging to form valve seat face. [14]

4. KEY ISSUE IN HEAT TREATMENT: ATMOSPHERE CONTROL

Protective atmospheres used for various heat treatment processes have experienced considerable changes over the past decade. Gas atmosphere generation started from charcoal, natural gas and liquid petroleum gases (LPG) have been used widely. While the generation of protective atmospheres used generators to convert its source gas to mixture of N_2, CO and H_2 which has been used up to date, in-situ gas generation methods have been developed and partly applied in industry. These have enabled the reduction of source gas consumption and processing costs. [30]

Atmosphere control methods that ensure precise controls have changed from the independent measurement of dew points, CH_4, CO or CO_2 to Oxygen sensor methods that enable continuous monitoring. However, a misfit is un-avoidable between atmospheric composition and deviations in the output current of oxygen sensors. This is caused by a deterioration of the sensor itself and also under through considerable changes of the atmosphere during processing. Therefore it is very dangerous to rely simply on an O_2 sensor. Therefore, the importance of precise atmosphere control measures, such as direct carbon potential measurement should be reminded to increase the reliability of case hardening process without resorting to gas or reduced pressure processes. Recent advanced measurement methods that enable continuous and accurate monitoring (In-situ and sample gas monitoring by Laser spectroscopy and High speed Gas-chromatograph method) have been developed and partly applied for heat treatment operations. These new methods enabled reliable control of the heat treat process which yields quality products with reduced waste gases.

4.1 Carbon potential control

4.1.1 Gas carburizing processes

Control of heat treatment atmosphere is quite important to produce quality products whether it is traditional gas or vacuum processes. However, the carbon potential (CP) control [23] of protective atmospheres is not done well in spite of long history for quenching, carburizing and carbonitriding that require precise atmospheric controls to prevent the occurrence of de-carburization, over carburizing and to introduce optimum compressive residual stresses. The diffusion depth and hardened case depth are influenced by the carbon potential of the atmosphere. CP is influenced by various factors such as furnace insulator materials, the state of sooting condition, gas composition, pressure, operating temperature, etc., and are not stable at any moment of the carburizing process as believed. [24]

Appropriate CP control enables the reduction of treating time and ensures the surface carbon concentration and diffusion pattern, which directly affect the state of the introduced microstructure, hardness and strength of treated components.

The up date technology that enables the more reliable results is an Infrared or a Laser gas analyzer for multiple elements, or in-situ carbon potential measurement method. [24, 30]

4.1.2 Reduced pressure carburizing (Vacuum carburizing)

Vacuum carburizing technology has advanced considerably. Continuous measurement of the carburizing condition under reduced pressure becomes possible through the emergence of newly developed in-situ or gas sampling methods (much the same as gas carburizing) and enables precise control of the carburizing process. [31]

Diffusion speed of carbon is directly affected by heat treatment temperature with higher temperatures increasing diffusion speed. The high temperature carburizing condition usually results in grain growth during treatment and necessitates the use of improved case hardening steel that enable the prevention of excessive grain growth to some extent. New vacuum carburizing grade steels containing about less than 0.1 percent of Ti and Nb increase the temperature limits of grain growth up to 1050 °C [32]

4.1.3 *High Pressure Gas Quenching*

The recent cooling technology using pressurized gas for quench hardening is advancing. However, the technology is not optimized to introduce sufficient hardness with distortion control. Usually, the cooling power of industrially applicable pressure for gas quenching is much slower than oil quench and aqueous solutions used for quench hardening. Additionally, when the cooling power is increased to give almost same hardness with the traditional quench methods, distortions will occur. Therefore the optimization of cooling technology should be done concurrently.

4.1.4. *Carbonitriding*

Nitrogen is an important alloying element in order to increase hardenability of steels. It is also effective in reducing the need for additional alloying elements. Carbo-nitriding methods have been used since the mid 1960's to case-harden automotive components, essentially to introduce high case hardness for low alloy and plain carbon steels. Typical examples of components include bushing clutch release forks and small universal joint cups. Up to about 1 percent nitrogen is very effective in increasing case hardenability and resistance against softening by the heat generated during operation by sliding or rolling fatigue phenomena. It is also effective to recover reduced surface hardenability created by grain boundary oxidation associated often in conjunction with the presence of Cr and Mn in steels. However, care should be taken to prevent excessive nitrogen concentrations in order to guard against pore formation caused by the escape of nitrogen gas from the component matrix. [23] New carbonitriding technology is recently developed for automatic transmission gears that contain finely dispersed carbide and strengthened by fine martensite matrix.[33]

4.1.5 *Low temperature nitrocarburizing and oxy-nitro-carburizing*

For more than thirty years the low temperature (570 ~ 580 !) cyanide salt bath nitriding process has been widely used in the automotive industry. The salt bath nitriding process not only forms a nitride compound layer at the component surface. Nitrogen also diffuses into the matrix and increases fatigue strength by over saturating nitrogen in the ferrite matrix structure. This method has been applied for thousands of automotive components made of low carbon grade iron base materials.

Salt bath nitriding, which uses cyanate instead of cyanide, was developed in the late 1960's to eliminate toxic and hazardous disposal problems. Also, operating temperatures widened from 400°C to 630°C to meet application needs and to optimize component properties. Stainless steels can be nitrided without deteriorating corrosion resistance while also increasing surface hardness up to Micro Vickers hardness (HV) 1000 or higher. [34]

The salt bath nitriding and gas processes have differences in N and C concentrations depending on the process used. Also, treatment times of these processes yield different results as a function of N, C and O concentrations.[35] Various types of low temperature nitriding processes using gas and specially designed liquid have been developed during the past decade.

A new Plasma nitriding technology was developed in Europe recently. New "Through cage" or "Active Screen Plasma: ASP" nitriding processes have yielded excellent results and may open a new market thus expanding the low temperature nitriding market.[36]

5. SURFACE MODIFICATION AND HYBRID HEAT TREATMENT

Different surface modification technologies available today to enhance the properties of components are listed in Tables 8 and 9 [37]. It has also necessitated the use of hybrid processes to fulfill the needs of this category of components. Dual heat treatment or heat treatment combined with an additional surface modification method are applied to meet special property requirements and applications. Most specifically, there are many popular combinations of surface modification methods such as phosphate treatment, vapor deposition and or solid lubricant coatings that have potential to satisfy unique combined property needs. [38]

A unique economical coating available with heat treatment is a coat quench technology. [38] including the one which has been used to improve surface friction coefficient for more than thirty years, and other methods to prevent rusting by forming surface oxide film during cooling into aqueous solutions.

5.1 Solid lubricant coatings

Various types of polymeric, metallic and composite coating films are applied to miscellaneous automotive components to improve friction and corrosion resistance. These are listed in Table 8. Thickness and coating type for materials are designed in accordance with the intentions of satisfying the specific components requirements and design at hand This coating is not a heat treatment, but it reduces surface friction property and is widely used surface modification process.

Coatings require special technologies that are processed in specified company or plant facilities to assure the quality of components processed. Depending on the applied methods, various process control measures become necessary. Throughout all processing stages, methods and procedures to monitor and control precise compositions and concentrations should be standardized within specified limit ranges to ensure that processed components meet their required properties.

6. EMERGING TECHNOLOGIES IN MATERIALS, HEAT TREATMENT AND SURFACE ENGINEERING

6.1 Materials

Social needs toward global environment, climate and energy conservation are the key factors which determine the technology choice today. In order to save fossil energy consumption, new vehicles such as hybrid power, fuel cell and electric cars are in the market since 2001, by the breakthroughs made by mass production of Toyota Hybrid cars. This trend will change the balance of materials used for production of auto-vehicles as well as the processing technologies. R & D efforts will be devoted to develop lighter and stronger materials such as light metals and plastics, while special steels will become the material of choice where durability and comfort are important.

Heat treatment requires fundamental research to develop ways to improve the components properties in terms of stiffness, strength, durability and wear resistance. At the same time energy conservation is possible through the optimum utilization of all possible technologies for example, to minimize heating energy, elimination of re-heating processes, better designs of burners/furnaces, lower processing temperatures, reducing processing time etc. Collaborative efforts amongst material manufacturers, automotive engineers and heat treatment engineers will be more productive.

Surface modification technologies will become more important since an optimum combination of base material property, and the property achieved through heat treatment and final surface modification technologies will provide better products. Ferrous, light metals, plastics and glass-ceramic materials should be used in optimum combination in order to introduce new grade of specific weight to strength ratio to satisfy the needs of the new century.

6.2 Carburizing and carbonitriding

- Reduced pressure carburizing needs additional technology to reduce processing time during heating and cooling which should be named as “The controlled Pressure Processing”
- High temperature reduced pressure carburizing with gas quench needs further technology to increase cooling power without increase in distortion.
- Necessary technologies are development of grain *growth controlled steel* by dispersed TiN, AlN and NbN precipitates and thermo-mechanical process control.
- Rare Earths influence seems to be important to reduce carburizing under reduced pressure and further investigations are needed [40-43]
- Processing time for specified effective case depth is directly influenced by *carbon potential* of the carburizing atmosphere even with reduced pressure methods, and standardization of process parameter should take carbon potential into account to enable reliable and efficient

Table 8
VARIOUS TYPES OF HYBRID HEAT TREATMENTS [39]

Hybrid types	1st heat treatment	2nd heat treatment or surface modification
Plural Heat treatments	Carburizing & hardening Nitrocarburizing,Nitriding	Surfurizing, Nitriding, Induction hardening Induction hardening,Oxidizing, PVD
Sintering base	Sintering and brazing Sintering	(simultaneous H.T.) Forging, Extrusion
Quenching and Tempering + Surface Coating	Quenching and coating (Simultaneous) Tempering andblackening	Rust proof, COF control coat, Rolling fatigue strength (Simultaneous H.T)
Coating +Heat treatment	Iron plasma spray Plating	Phosphate coat Diffusion treatment

PVD- Physical Vapor Deposition. COF- Coefficient of Friction.

Table 9
SURFACE MODIFICATION METHODS APPLIED FOR AUTOMOTIVE COMPONENTS. [39]

Methods	Modification type	Thickness(im)	Property	Typical application
Electrolytic plating	Cr, Cu, Ni, Zn-Fe, Zn-NiNi-P-SiC BNFe, Sn Ni-P-B	100 ~300 10 ~ 1005 ~ 20	Corrosion resistance, outlook, low COF, resistance to wear, scuff and micro-welding	Bumper, Ornaments, Body component panels Cylinder bore, Piston
Electro-less, Conversion	Ni-P-SiC Phosphate coat	3 ~ 20	Wear resistance	Brake cylinder pistons
Electrolytic deposition	FeS, Fe_2S Phosphate coat	3 ~ 820 ~ 50	Reduce friction Lubrication	(Developing) Cold forming blanks
Coat quench	Gr, Phosphate, MoS_2 etc x PIA, PE etc	4 ~ 7	Prevent rusting, Adjust friction coefficient.	Fasteners, Vv spring retainers, etc.
Solid lubricant coat	MoS_2, Graphite, PTFE, hBN x PAI, Epoxy	3 ~ 100	Reduce friction Dry lubrication	Piston rings, Carburetor shafts,Gears, Pistons
Painting	Color paints	30 ~ 500	Outlook, Corrosion resistance	Body and panels and various components
Plasma spray	Fe, Cr, Al, Mo, Ceramics, W, WC, Cu, Cu-Zn,	100~ 400	Wear resistance, Thermal insulation	Piston ring, Lifter periphery, O_2 sensor, (Cylinder bore)
PVD Physical vapor deposition	TiN, CrN, TiAlN, TiAlCN	4 ~ 20	Wear, Seizure resistance	Lifter shim, Piston rings, Tools & dies for Machining & forming
CVD	DLC,	2 ~ 10	Reduce wear and friction	(Piston rings)
Dip coating	Zn, Zn –Ni, Zn-Al	50 ~ 300	Corrosion resistance.	Body sheet panels Fuel tank

COF: Coefficient of Friction. hBN: Hexagonal Boron Nitride. DLC: Diamond Like Carbon.

carburizing. Therefore the development of the more precise carbon potential control methods is necessary.

- To increase the processing efficiency, it is important to increase surface activity with new concept by adopting catalytic or REDOX reaction.

6.3 New nitriding methods for aluminum

Surface activity control is very important to increase nitriding power that is not well understood and needs further investigation. Reduction and oxidation phenomena are seems to be related with particular results observed in some cases will be a key to break through traditional processes.[44] Atmosphere and plasma control are other possible methods to increase surface reactivity. [45]

6.4 Nitriding of stainless and maraging steels

A patent on gas nitriding of maraging steel by controlled dissociation method claims high nitriding speed as compared with other processes.[39] Addition of rare earth elements would enhance diffusion rates [40-43].

7. CONCLUDING REMARKS

An overview of the materials as well as the heat treatment and surface technologies that are currently being used for automotive applications is presented in this paper. There is a need for further R&D efforts towards developing eco-friendly technologies for accomplishing the industry requirements of higher fuel efficiency, comfort, safety, durability, cost and emission norms. International collaborative efforts on the line of ULSAB-AVC are very much needed to meet the challenges facing the auto industry.

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