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Effects of Heat Treatment on Materials Used In Automobiles: A Case Study

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Abstract: *Automobile sector is one of the most thriving sectors in today's date. Increasingly, need of the hour requires automotive industry to be more environmentally responsible and fuel efficient with respect to their products and processes; reasons include regulatory requirements, product stewardship, public image, and potential competitive advantages. This paper presents an exploratory study of the effects of heat treatment on materials used in automobiles, major ones being steel and aluminium. This paper addresses the benefits of heat treatment on metals like aluminium on a comparative basis and stresses upon the application of same in automobile parts. Findings suggest that if aluminum is subjected to various heat treatment processes, its physical properties get remarkably enhanced which justifies its trendy use in modern world. These specific findings can be helpful to engineering and automotive industry managers as they respond to environmental and competitive demands entailing quality assurance.*
Key words: *Heat treatment, attrition, annealing, normalizing, tempering*

I. Introduction

In recent years there has been considerable growth in road transport, and this trend is set to continue for the foreseeable future . Today's transport is based almost exclusively on the consumption of petroleum products such as gasoline and diesel, and is responsiblefor producing more than 20% of overall anthropogenic CO_2 emissions[8]. In recent decades vehicles have undergone several changes towards more environmentally friendly transport. Some of these changes are a matter of technology developments and cost optimisation, but many were driven by government interventions such as emission legislation. Modern industrial operations face relentless environmental and economic pressures: efficient use and management of resources and energy, emissions reduction, process reliability[11]. These challenges can only be addressed by constantly improving methods and process technology. In the automotive field, for example, improved heat treatment processes increase the strength and toughness properties of metallic structural components, and modern surface engineering technologies reduce the effects of abrasion and attrition[10].

1.1 *Heat treatment and its effects*

Heat treatment is a controlled process used to alter the microstructure of materials such as metals and alloys to impart properties which benefit the working life of a component, for example increased surface hardness, temperature resistance, ductility and strength. There are various types of heat treatment processes major ones being annealing, normalizing, tempering and hardening. Annealing is basically a stress relieving process in which material is heated at a temperature above its upper critical temperature and is cooled in furnace itself. Normalizing is a grain refining process in which material is heated just like annealing but is cooled in still air. Hardening is the process of heating the metal well above the upper critical temperature and then quenching it in medium like oil and water. Tempering comprises reheating of previously hardened material to increase its toughness by heating it below the lower critical temperature of the material and then cooling it in air. The property of the substance is the function of its grain structure and therefore refined grain structure imparts better strength and reliability after undergoing heat treatment.

II. Modern approach and considerations in automobile materials

Until 19th century the dominance of steel ruled the automobile sector. Over the years the automobile sector underwent subtle change in terms of materials employed and gradually in 21st the industry it is at the verge of vintage Aluminium. A modern car with components made of aluminium can be 24 percent lighter than one with components made of steel, which also allows fuel consumption to be reduced by 2 litres per 100 kilometres which in turn will curtail the emission of poisonous gases like CO_2 and CO. Advanced high-tensile aluminium alloys can now completely supersede steel that has conventionally been used to make a vehicle body, the most important car component. This was proved by Audi engineers, who in 1994 released a passenger A8 model with the complete body made of aluminium. The model showed a weight reduction of 239 kg[8].

2.1 Past trends in weight and materials of a typical passenger car

TABLE -2.1

Model of Toyota	Weight(kg)	Iron & steel	Cast iron	Non ferrous	rubber	plastics	glass
1968	1020	75	11.8	5.0	3.6	2.6	3.0
1978	1144	75.7	10.1	7.8	3.0	3.0	2.4
1988	1300	73.7	10.4	7.2	7.1	7.1	2.6
1992	1290	71.7	10.3	9.2	7.5	7.5	3.1
1996	1313	69.8	10.2	10.4	9.2	9.2	2.9
2000	1371	68.7	8.2	10.6	9.0	9.0	2.6

The above table shows the weight of different materials in a typical Toyota model over the years[2]. The interesting trait that can be observed is that inspite of the increase in the weight of vehicle the percentage of steel has decreased on the other hand the composition of non-ferrous metals like aluminium has increased.

2.2 *Aluminium and Automotive industry.*

Aluminium is a light and soft white metal with a frosted silver tint due to a thin oxide film which covers it on contact with air. It is located in the III group of the periodic table and is defined by the symbol, Al. Its atomic number is 13, its atomic mass, 26.98154, and its melting point is 660°C. Aluminium is widespread in nature: it is the fourth most common of all the elements and the first most common of all metals (making up 8.8% of the Earth's crust), but it is not found in pure form. It is mainly extracted from bauxite, although there are several hundred aluminium minerals (aluminum silicates, alum stones, etc.), the majority of which are not suited to produce the metal. Aluminium is forgeable and malleable. Its oxide film makes it resistant to corrosion and this means that the life of aluminium goods is very long. In addition, it has a high electrical conductivity, is non-toxic and is easily reprocessed. Today aluminium is the second most used material (in percentage terms) of the total weight of the car. It is used to make components of the suspension, the chassis, cylinder blocks and other engine components. It is believed that 1 kg of aluminium can replace up to 2 kg of steel and cast iron in many areas of application. The corrosion process enables aluminium particles to penetrate the structure of steel and form a reliable adhesion. The new cutting-edge technology opens broad prospects for the automotive industry to produce combined aluminium-and-steel bodies for cars with partial use of welding instead of clamps. It enhances durability and reliability of structures, making them more light-weight at the same time.

III. Experimental Investigation

An experiment was conducted to illustrate the effect of heat treatment on materials used in automobile. The metal selected was aluminium 6xxx alloy because of its extensive use in automobile sector . The hardness reading of the testpiece was taken prior to and after heat treatment to observe the significant changes occurring in its properties especially hardness to justify the trendy use of aluminium in modern era.

3.1 *Specimen preparation*

As mentioned earlier an aluminium alloy 6xxx billet was taken for studying the effects of heat treatment on metal that is used modern vehicles extensively. The aluminium billet was carried to fitting shop where it was figured to proper dimension and then cut into four equal parts of same dimension, thereafter it was subjected to grinding as shown in the following figure 3.1

Fig.3.1 Aluminium 6xxx alloy test pieces

3.2 ***Apparatus used***

(a) Muffle furnace (sometimes, retort furnace) in historical usage is a furnace in which the subject material is isolated from the fuel and all of the products of combustion including gases and flying ash. After the development of high-temperature electric heating elements and widespread electrification in developed countries, new muffle furnaces quickly moved to electric designs. Today, a muffle furnace is (usually) a front-loading box-type oven or kiln for high-temperature applications such as fusing glass, creating enamel coatings, ceramics and soldering and brazing articles. . They are also used in many research facilities, for example by chemists in order to determine what proportion of a sample is non-combustible and non-volatile (i.e., ash). The muffle furnace used had following specifications:

- Maximum temperature – 1200 degree celsius
- Maximum voltage-220 volts
- Maximum Load- 3.5 kilo watt

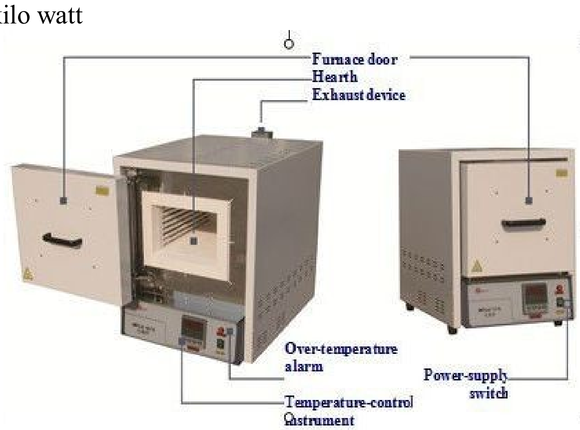


Fig. 3.2(a) Typical muffle furnace heater.

(b) The Brinell hardness tester used was OPAB-3000 with optical magnification of 14x. Most commonly it is used to test materials that have a structure that is too coarse or that have a surface that is too rough to be tested using another test method, e.g., castings and forgings. Brinell testing often use a very high test load (3000 kgf) and a 10mm wide indenter so that the resulting indentation averages out most surface and sub-surface inconsistencies. The Brinell method applies a predetermined test load (F) to a carbide ball of fixed diameter (D) which is held for a predetermined time period and then removed. The resulting impression is measured across at least two diameters – usually at right angles to each other and these result averaged. The mathematical formula is given as

$$BHN = 2 P / (\pi D (D - (D^2 - d^2)^{1/2})) \qquad (1)$$

where

BHN = Brinell Hardness Number

P = load on the indenting tool (kg)

D = diameter of steel ball (mm)

d = measure diameter at the rim of the impression (mm)

The Brinell hardness tester used had following specifications:

- Loads in kgf - 500 to 3000 kgf in steps of 250.
- Initial load – Nil

- Maximum test height x throat (mm) - 380 x 200
- Maximum depth of elevating screw below base in mm – 180
- Machine Height in mm – 1250
- Size of base in mm- 400 x 740
- Drive motor in HP – 0.5
- Mains Supply – 3 Phase, 415 v, 50 Hz A.C
- Indentation measurement - Direct reading optical drive with 14x magnification

Fig.3.2(b) Brinell hardness tester.

3.3 Procedure

The test piece used was aluminium 6xxx i.e Al –Mg-Si alloy. It was cut into 4 equal parts and grinded properly prior for heat treatment. Thereafter, the workpieces were carried to Composite Material laboratory and first of all two of them were kept in the muffle furnace which was set at a temperature of 300 and 350 degree Celsius respectively and the test pieces were left for 1 hour at the elevated temperature for carrying out annealing and hardening(quenching) operations. After 1 hour the one of the two pieces was taken out of the furnace and quenched immediately in water and the other one was left in the furnace itself for the furnace cooling i.e for carrying out annealing process. The other day remaining two pieces were kept in the muffle furnace at 300 degrees for one hour. After one hour one was immediately quenched in water for carrying out successive tempering operation and the remaining one was left to cool in the air for carrying out Normalizing operation. Next the quenched material was again kept in muffle furnace at a temperature of 200 degrees for carrying out tempering operation to remove internal stresses. The voltage in the above mentioned case was maintained at 220 volts and the load was 3.5 kilo watt.

Fig 3.3 Muffle furnace containing workpieces for heat treatment

3.4 Observation and Results

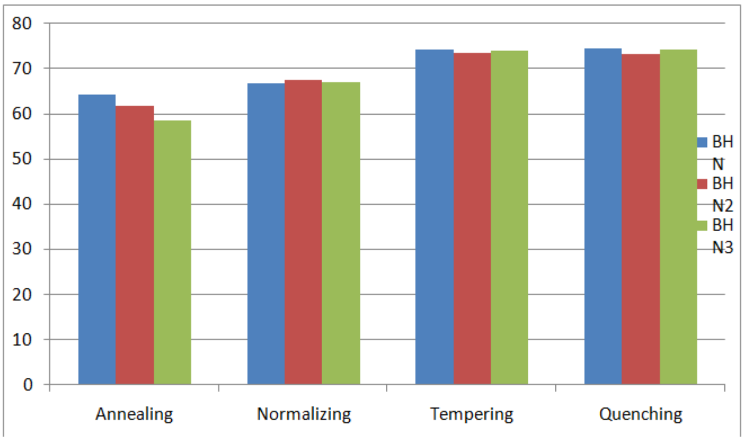
The reading was taken and BHN was found out using the above stated formula with the ball of both 5mm and 10 mm diameter and at load 750 kgf and 1000kgf respectively . The results and observations are shown in the table from which certain effective conclusion can be drawn as to why aluminium is used extensively in automobile parts besides good strength to weight ratio and certain graphs will make it clear and more precise based on the table 3.4(a) which is given prior to heat treatment and Table 3.4(b) which is given after heat treatment.

TABLE 3.4(a)- Showing results of hardness test prior to heat treatment

SL.NO	Diameter of ball used	Process carried out on workpiece	Diameter of indentation formed	Force applied	BHN
1.	10mm	None	2.76mm	500kgf	63.4
2.	10mm	None	2.72mm	500kgf	64.0
3.	10mm	None	4.17mm	1000kgf	69.6
4.	10mm	None	4.20mm	1000kgf	68.4

TABLE 3.4(b)- Showing results of hardness test post heat treatment

SL.NO	Diameter of ball used in mm	Process carried out on workpiece	Diameter of indentation formed in mm	Force applied in kgf	BHN
1.	10	Annealing	4.33	1000	64.6
2.	10	Annealing	4.44	1000	62.0
3.	10	Normalizing	4.27	1000	66.5
4.	10	Normalizing	4.24	1000	67.5
5.	10	Tempering	4.05	1000	74.3
6.	10	Tempering	4.07	1000	73.5
7.	10	Quenching	4.04	1000	74.0



3.5 Bar Graph Showing the Hardness of Aluminium 6xxx specimen after various heat treatment processes based on observation table

IV. Conclusion

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. Also it is seen that in the long run if the heat treatment of automotive parts is carried out along with fuel type modification , it can really prove to be a boon for the industry. Based on the experimental analysis and results of 6xxx aluminium test piece it can be concluded that:-

1) The experimental analysis revealed some remarkable feature like heating the aluminium alloy well below its melting point i.e 300 to 400 degrees and then carrying out processes like normalizing, tempering and quenching greatly causes change in grain structure and thereby causing change in its properties of hardness. 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.
2) Less mass, so that vehicles made with aluminum weigh less, perform better, are more agile and consume less fuel.
3) Strength of specially developed alloys is comparable to steel when properly treated and formed, so it can support the vehicle structure and be more easily engineered to deliver superior safety for passengers in the event of a crash.
4) Excellent formability, so it enables automakers to deliver the distinctive design that defines their brands.
5) Versatility that enables it to be joined with other metals or combined with materials like plastics and fiberglass to enhance specific properties.

6) Resistance to corrosion, which can be enhanced with specialized coating, painting and treatment, for a long functional life.
7) Aluminum is infinitely recyclable which makes it the consumers' material choice in light of ecologic advantages and sustainability.

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