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Optimization of Process Variables in Gas Carburizing Process: A Taguchi Study with Experimental Investigation on SAE 8620 and AISI 3310 Steels

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Abstract

The utilization of surface engineered materials in various engineering fields has undergone a tremendous increase in recent years, and the need for proper surface engineering of materials has thus increased enormously. However, the knowledge acquired in conventional heat treatment processes, cannot be applied to surface heat treatment processes, of which the hardenability is completely different from that of conventional hardness.

Gas carburizing is one of the surface engineering techniques widely used in the process of surface hardening of critical components used in automobile engineering. In this method, the surface composition of the low carbon steel changes by diffusion of carbon and results in a hard outer surface with good wear resistance properties. Fatigue behavior of case hardened parts depends to a great extent on the correct combination of hardness penetration depth and the magnitude of hardness at and beneath the surface with low size and shape distortion.

Surface engineering is a complex process in itself, as a number of variables affect the success of the process and quality of the components. One industrial survey indicates that there is a rejection of 10% - 12% of case hardened components due to various defects. Quality control is one way to minimize the percentage rejection. Quality control is possible through hardening the components under optimal conditions. This study aimed to optimize the surface hardness and case depth of SAE 8620 and AISI 3310 steel materials. The Taguchi method is a powerful tool in experiment design for the optimization process. An orthogonal array and ANOVA were employed to investigate the influence of major parameters on surface hardness and case depth. Optimum conditions were achieved by applying high hardness and high penetration depth.

Key words: Quality, Gas carburizing, Process variables, Optimization, Taguchi method.

Introduction

Surface Engineering

The engineering of surfaces of components to improve the life and performance of parts used in automobiles and aerospace engineering is an active area of research. Suitable thermal / mechanical / thermomechanical surface engineering treatments will produce extensive rearrangements of atoms in metals and alloys and a corresponding marked variation in physical, chemical and mechanical properties. Among the more important of these treatments are heat treatment processes such immersion hardening, induction hardening and case carburizing (Child, 1980).

Gas carburizing is a surface hardening method in which the surface of the components is saturated with carbon in a gaseous atmosphere containing carbon. To accomplish this, the components are first heated in a neutral atmosphere to a predetermined temperature in the range of 870 to 940 °C. Then the furnace is flooded with a suitable gas such as propane, butane or methane. Finally, the components are held at this temperature to allow for the diffusion of carbon into the case. After the carburizing treatment is completed, the components are quenched to obtain the required hardness, wear resistance and fatigue resistance on the surface, supported by a tougher core.

A striking feature of the gas carburizing process is that the original toughness and ductility remain unaffected even after the heat treatment (Rajan et.al., 1994).

Materials selection and composition

At present, a number of steels are available for specific applications. In fact, the selection of suitable steel from an economic standpoint has become an important function of a scientist or engineer (ASM Metals Handbook, 1981).

In the present study SAE 8620 and AISI 3310, steels were used to compare and analyze the results of the Taguchi design.

SAE 8620	**AISI 3310**
C 0.18% - 0.23%,	C 0.15%
Si 0.2% - 0.35%	Si 0.1% - 0.35%
Mn 0.7% - 0.9%	Mn 0.3% - 0. 6%
Cr 0.4% - 0.6%	Cr 0.6% - 1.1%
Co 0.15% - 0.25%	Ni 3.0% - 3.75%
Ni 0.4% - 0.7%	

Taguchi Design

There is a unique statistical experimental design technique known as Taguchi's Robust Design method. The design of parameters using Taguchi's method is an offline quality control method. Offline quality control methods are quality and cost control activities conducted at the product and process design stages to improve product manufacturability and reliability and to reduce product development and lifetime costs (Philip, 1988).

Parameter design can be used to make a process robust against sources of variation and hence to improve field performance. In Taguchi's concept, the product must be produced at optimal levels with minimal variation in its functional characteristics. Control and noise factors affect the product quality. The former can be easily controlled although noise factors are nuisance variables that are expensive to control.

In order to achieve case hardened steel components, a parameter optimization study was carried out in a gas carburizing furnace by subjecting SAE 8620 and AISI 3310 steel specimens to the gas carburizing process.

Background

Automobile components such as rack and pinion, gears, cam shaft valve rocker shafts and axles, which require high fatigue resistance, are normally case hardened by gas carburizing. Gas carburizing is carried out in retort type, sealed quench type and continuous pusher type furnaces. These furnaces are either gas fired or electrically heated. The gas carburizing temperature varies from 870 to 940 °C the gas atmosphere for carburizing is produced from liquid or gaseous hydrocarbons such as propane, butane or methane (Rajan et.al., 1994). The study of process parameters in metals during heat treatment has been of considerable interest for some years (Denis, 1987; Leblond, 1989; Yang et.al., 1997; Liu et.al., 2003) but there has been relatively little work on process variables during the surface hardening process (Xu and Kuang, 1996) since controlling parameters in gas carburizing is a complex problem. The major influencing parameters in gas carburizing are the holding time, carburizing temperature, carbon potential and the quench time in oil (Shewmon, 1963). The attainment of the correct combination of surface hardness and effective case depth requires the use of proper and optimized process variables. It is therefore desirable for industries/ researchers to explore the possibility of optimizing the process variables to achieve quality in gas carburizing applying Total Quality Management (TQM) concepts. This was the objective of the present investigation.

Experimental Procedure

The investigation was performed on cylindrical pinion samples (Figure 1) (diameter 15 mm and length 250 mm) of SAE 8620 and AISI 3310 steels in a 3.5 m depth, 130 kW, methanol-acetone Unitherm gas carburizing furnace with oil as the quenchant.

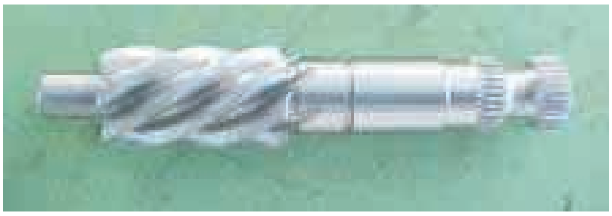
The 4 process variables, namely holding time, carbon potential, carburizing temperature and quenching time, which affect the hardness and case depth were selected for the Taguchi design.

A L9 (3^4) orthogonal array design was adopted for experimentation for each steel material.

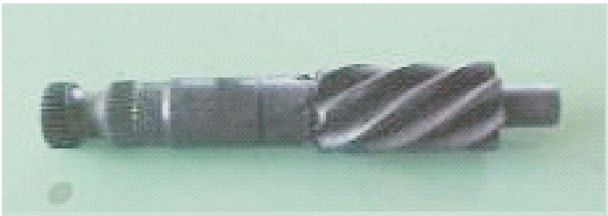
The 18 experiments (9 experiments for each material) were conducted by varying all the parameters (conditions adopted in experimentation are shown in Table 1) identified to study the influence of these parameters (between low, medium and high) on surface hardness, case depth, and every case hardened component was taken to measure the surface hardness and case depth. The results of the L9 array in Tables 2 and 3.

The surface hardness (HRA) was measured using a Rockwell hardness tester. A scale with a load of 600 N, and case depth (HPN) in millimeters was determined through visual metallurgical examination.

Thermal damage and cracking were tested by visual examination, metallographic test, crack detector test, and surface appearance test, and the resulting microstructures are shown in Figures 2 and 3.

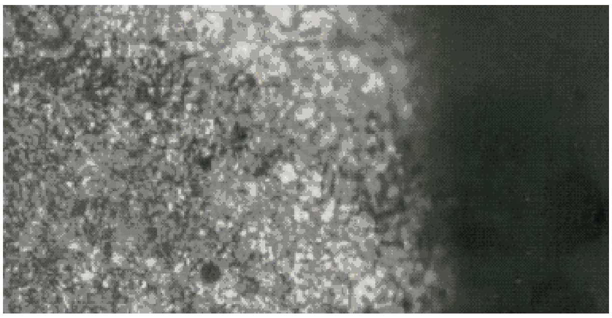


Component before heat treatment

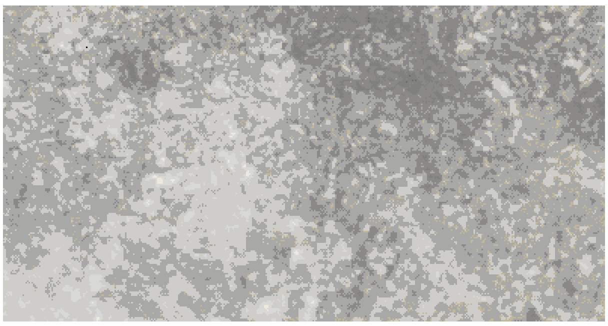


Component after heat treatment

Figure 1. Samples used in the experimentation.



Case region

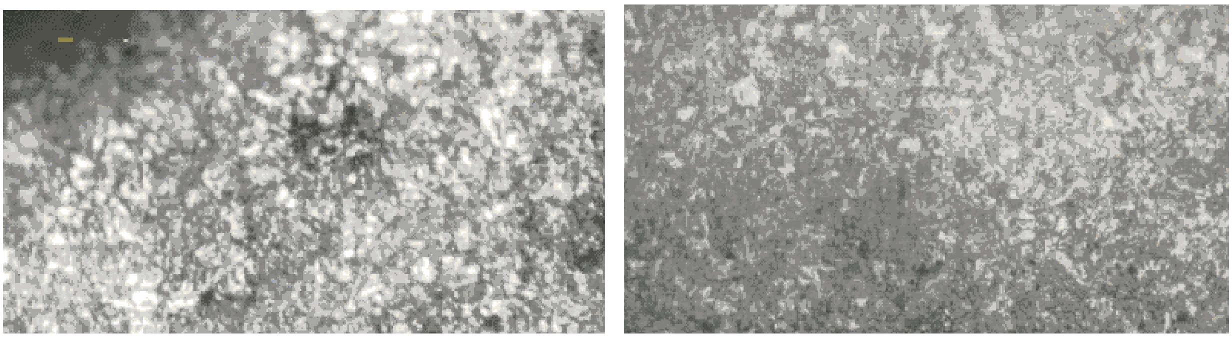


Core region

Figure 2. Microstructure of heat treated pinion samples of SAE 8620.

Table 1. Operating range of parameters of GCF.

Serial Number	Parameters	Notations	Unit	Value with Range
01	Holding time	HT	min	180-210
02	Carbon potential	CP	mV	1110-1120
03	Carburizing temperature	CT	°C	870-930
04	Quenching time	QT	min	20-30



Case region Core region

Figure 3. Microstructure of heat treated pinion samples of AISI 3310.

Table 2. L9 Orthogonal array of gas carburizing process parameters and test results for SAE 8620 material.

Experiment Number	Holding Time	Carbon Potential	Carburizing Temperature	Quenching Time	HRA	HPN
01	180	1110	870	20	80	0.9
02	180	1115	900	25	81	0.7
03	180	1120	930	30	82	0.7
04	195	1110	900	30	81	0.9
05	195	1115	930	20	79	1.0
06	195	1120	870	25	80	1.1
07	210	1110	930	25	81	0.8
08	210	1115	870	30	81	0.9
09	210	1120	900	20	82	1.0

Table 3. L9 Orthogonal array of gas carburizing process parameters and test results for AISI 3310 material.

Experiment Number	Holding Time	Carbon Potential	Carburizing Temperature	Quenching Time	HRA	HPN
01	180	1110	870	20	79	0.8
02	180	1115	900	25	80	0.7
03	180	1120	930	30	80	0.7
04	195	1110	900	30	81	0.9
05	195	1115	930	20	79	0.9
06	195	1120	870	25	79	1.0
07	210	1110	930	25	81	0.8
08	210	1115	870	30	82	0.9
09	210	1120	900	20	79	1.0

Results and Discussion

Case Study – I: Optimization of process variables for SAE 8620 material

ANOVA was used to determine the influence of the main parameters at a 3-factor level and the percentage contribution of each parameter. The average effect of the main parameters on surface hardness and case depth/HPN are shown in Tables 4 and 5.

Table 4 indicates that the carburizing temperature does not have any effect on the surface hardness. The percentage contributions of holding time (22%), carbon potential (21%), carburizing temperature (1%), and quenching time (56%) indicate that the quenching time has the most influence on surface hardness.

Table 4. Average effect of main parameters at a 3-factor level on surface hardness (HRA).

Parameter	Low	Medium	High
Holding time	80.56	80.70	80.66
Carbon potential	81.30	81.32	79.33
Carburizing temp.	81.00	81.00	80.50
Quenching time	80.00	81.50	81.00

Table 5. Average effect of main parameters at a 3 - factor level on case depth (HPN).

Parameter	Low	Medium	High
Holding time	0.81	0.92	0.90
Carbon potential	0.80	0.88	0.90
Carburizing temp.	0.89	0.86	0.80
Quenching time	0.87	0.80	0.83

Table 5 indicates the influence of gas carburizing process parameters on case depth. Holding time in the furnace has the most influence (65%) on the case depth, as the percentage contributions of carbon potential, carburizing temperature and quenching time are 9%, 14% and 10%, respectively. The error is 2%.

The optimum process conditions were obtained by employing the "higher the better" (high surface hardness and high case depth) strategy.

Case Study – II: Optimization of process variables for AISI 3310 material

Table 6. Average effect of main parameters at a 3-factor level on surface hardness (HRA).

Parameter	Low	Medium	High
Holding time	79.66	79.66	80.66
Carbon potential	80.33	80.33	79.33
Carburizing temp.	80.00	80.00	80.00
Quenching time	79.00	80.00	81.00

Table 6 indicates that carburizing temperature has no effect on surface hardness. The percentage contributions of holding time (20%), carbon potential (20%), carburizing temperature (0%), and quenching time (60%) indicate that the quenching time has the most influence on surface hardness.

Table 7 indicates the influence of gas carburizing parameters on case depth. Holding time in the furnace has the most influence (67%) on the case depth, as the percentage contributions of carbon potential, carburizing temperature and quenching time are 9%, 15% and 8%, respectively. The error is 1%.

The optimum process conditions were again obtained by employing the "higher the better" (high surface hardness and high case depth) strategy.

Table 7. Average effect of main parameters at a 3-factor level on case depth (HPN).

Parameter	Low	Medium	High
Holding time	0.73	0.93	0.90
Carbon potential	0.83	0.83	0.90
Carburizing temp.	0.90	0.86	0.80
Quenching time	0.90	0.83	0.83

Conclusion

- Time parameters have more influence on the quality of case hardened components, irrespective of the type of material,

- The present analysis indicates the optimum process conditions to obtain

  a) High surface hardness: Holding time 210 min, quenching time 30 min, carbon potential 1110 – 1115 mV, carburizing temperature 870-930 °C

  b) More case depth: Holding time 195 -210 min, quenching time 30 min, carbon potential 1110-1115 mV, carburizing temperature 870-930 °C,

- Comparison of the hardness and case depth of AISI 3310 and SAE 8620 shows that the latter has a greater hardness and case depth since alloy addition is greater,

- The confirmation of the experiment shows that the observations are within a 95% confidence level. The error in the experimental analysis is very low, and hence Taguchi's techniques can be applied to determine the optimum process parameters of gas carburizing in order to achieve quality components,

- Microstructural and microhardness studies were performed on selected specimens and it was determined that there were no defects in the carburized specimen.

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