Reduction of Cracks in the Cylinder Liners Choosing Right Process Variables by *Taguchi Method*

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ABSTRACT

This paper highlights the ***reduction of heat treatment cracks*** *in the cylinder liners. Zyglo test was conducted on the cylinder liners to obtain the attribute data. The effect of process parameters and subsequent reduction of cracks have been performed by Taguchi method. The analysis indicates that the heat treatment time by itself causes a change in the crack rate at the 90% confidence level. A confirmation test was also carried out to validate conclusions drawn during the analysis.*

1. INTRODUCTION

A true high quality product will have a minimal loss to the society as it goes through its life cycle. If a product does not perform as expected, the customer/manufacturer senses some loss. After a product is shipped, a decision point is reached; it is the point at which the manufacturer cannot do anything to the product. Before shipment, the manufacturer can use expensive or inexpensive materials/processes; but once shipped, the commitment is made for the product expense during its life cycle.

The problem of cylinder wear in the engines is a very acute one. The solution to this has been found in the use of cylinder liners, which can be replaced when these are worn out. They are made in the form of barrels from special alloy iron containing silicon, manganese, nickel and chromium. These are centrifugally. The cylinder liners are further hardened by heat treatment.

The heat treatment process of liners to increase wear resistance consists of hardening and tempering. Cylinder liners machined to the point of finishing were given the following heat treatment (*old cycle*):

- Heat to 875^{o}C in 30 minutes
- Hold at 875^{o}C temperature for 25 minutes
- Quench into Oil (still) at 80^{o}C
- Cool
- Temper at 210^{o}C for 1 hour and cool.

The cylinder liners treated according to this schedule are being used in diesel engines and heavy gas engines because of wear resistance superior to that of unhardened ones. The old process was modified increase the productivity of liners and to reduce cracks in the liners due to heat treatment. The new process is as follows:

- Heat to 900^{o}C in 30 minutes
- Hold at 900^{o}C temperature for 20 minutes
- Quench into Oil (still) at 80^{o}C
- Cool
- Temper at 210^{o}C for 1 hour and cool.

An experimental study has been carried out to analyze the performance of the new process of heat treatment developed for the cylinder liners. The performance of the new process was evaluated in terms of cylinder liner cracks using *Taguchi* method.

2. EXPERIMENTAL PLANNING

160 cylinder liners were used in the present investigation. 8 trials were employed with a sample size of 20 liners to study the heat treatment cracks. Zyglo (Fluorescent-penetrant) test was conducted to detect the cracks, if present, in the cylinder liners.

2.1Zyglo Test: Liners to be tested are first treated with a penetrant by spraying. The liquid penetrant is drawn into cracks. After the penetrant has had time to seep in, the portion remaining on the surface is removed by washing with a cleaner. This leaves the penetrant in all cracks. The liner is now treated with a developer. This developer acts like a sponge drawing the penetrant from the crack and enlarging the size of the area of penetrant indication. A combination of red penetrant and developer is used.

2.2 Selection of Process Parameters and their Levels: The process parameters that may cause cracks in the liners during heat treatment are:

- Temperature
- Time (i.e. Duration of heating and holding)
- Quenching

The upper and lower levels of parameters are given in *Table – 1*. To investigate all the factors, two at a time, for all possible combinations required six different experiments with 24 different conditions. using Taguchi orthogonal arrays (L8OA) all these aspects can be investigated with only 8 different conditions.

Table - 1
Parameter Levels

Parameter	Unit	Symbol	Level 1	Level 2
Temperature	°C	A	875	900
Time	min.	B	55	50
Quenching	_	C	Still Oil	Oil Agitated

2.3 Assignment of Parameters to an Orthogonal Array: The parameters were assigned to an L8 OA with the assignment and experiment results shown in Table – 2. Twenty (20) cylinder liners were used for each of the trial conditions.

Table - 2
Cylinder Liner Cracks - OA Assignment

Trial No.	Parameters and Interactions A 1	B 2	AXB 3	C 4	AXC 5	BXC 6	AXBXC 7	No. of Liners Cracked	Good
1	1	1	1	1	1	1	1	3	17
2	1	1	1	2	2	2	2	1	19
3	1	2	2	1	1	2	2	2	18
4	1	2	2	2	2	1	1	1	19
5	2	1	2	1	2	1	2	4	16
6	2	1	2	2	1	2	1	3	17
7	2	2	1	1	2	2	1	1	19
8	2	2	1	2	1	1	2	0	20

2.4 Attributed Data: Two-class attribute data was developed to analyze cracks in the liners. This is corresponding to an *all-or-nothing* characteristic, which can be numerically represented by a 1 (one) or 0 (zero). In this case, the number of occurrences in both classes is known. In the analysis, the lower number of occurrences of defective liners are treated as better characteristic.

Cracked and good liners are represented by 1 (one)s and 0 (zero)s respectively. Therefore, the data for the first trial is *three* 1 (one)s and *seventeen* 0 (zero)s.

3. ANALYSIS AND DISCUSSION

A summary of the ANOVA results is shown in Table -3. In the ANOVA analysis it is found that time is more significant parameter. Time by itself causes a change in defective rate at the 90% confidence level, and temperature by itself causes no change in defective rate. The temperature – time interaction is quite at the 90% confidence level. The quenching effect is also not much significant at the 90% confidence level.

Table - 3
ANOVA Summary using 0.1 Attribute Data

Source	Sum of Squares SS	Degrees of Freedom V	Variance V	Fisher Ratio F	% Contribution P
A*	0.006	1	0.006		
B	0.306	1	0.306	3.68+	1.64
AXB	0.156	1	0.156	1.88	0.54
C	0.156	1	0.156	1.88	0.54
AXC*	0.006	1	0.006		
BXC*	0.006	1	0.006		
AXBXC*	0.006	1	0.006		
e*	12.952	152	0.085		
Total	13.594	159			100.00
*pooled	12.976	156	0.083		97.28

* Items used to generate the pooled error estimate
\+ at least 90% confidence

Table – 4 shows the main effects of parameters. Looking at the difference column, parameter B (time) has the largest effect (7), parameter c (quenching) and interaction of A and B (temperature and time) have the second largest effect (5), and all other parameters have a weak effect or no measurable effect. It also can be seen from Fig.1 that the effect of time on crack rate is greater than that of temperature and quenching. The parameter's strength is directly proportional to the slope of the graph.

Table - 4
Main Effects of Parameters and Interactions

Source	Sum 1	Sum 2	Difference
A	7	8	1
B	11	4	-7
AXB	5	10	5
C	10	5	-5
AXC	8	7	-1
BXC	8	7	-1
AXBXC	8	7	-1

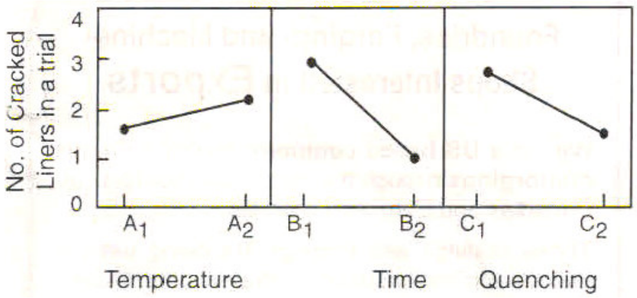

Fig.1: Liner cracks Experimental Plot

A plot of interaction between temperature and time is also shown in Fig.2. In this plot, there exist non-parallel lines which indicate the presence of an interaction. The parameter A (temperature) effect depends on the level of parameter B (time) and vice versa. The B effect is the largest; the AXB effect next largest; and the A effect is very small. The average of all results under A1 and all results under A2 are not very different and the average of all results under B1 and all results under B2 are different.

Therefore, the parameter B (time) must be kept at level 2 to reduce cracks in the cylinder liners. As the quenching effect is little considerable, it can also be maintained at level 2(i.e. the oil is agitated during quenching operation). The temperature can be kept at any level. The optimum parameters and their levels are given table-5.

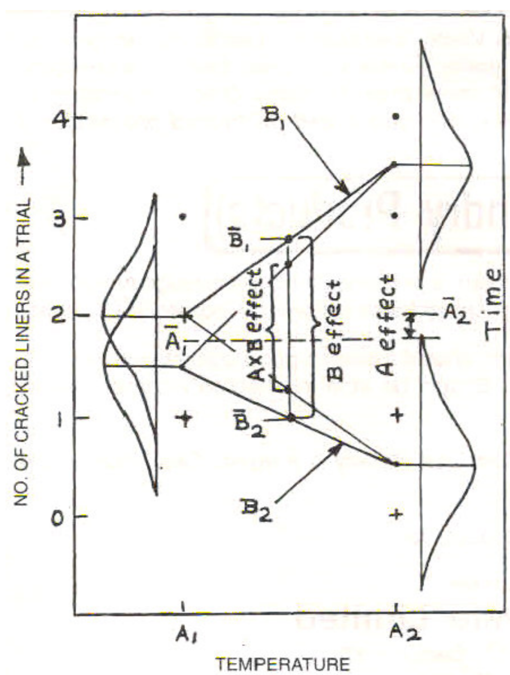

Fig. 2: Temperature – Time Interaction and Magnitude of Parametric Effect

Table - 5
Optimum Parameters and their Levels

Temperature	900 °C
Time	50 min.
Quenching	oil (agitated)

The confirmation test was also carried out to validate the conclusions drawn during the analysis phase. The optimum number of cracks is predicted (Appendix) at the selected level of significant parameters. The significant parameter is time. The predicted number of racks with time at level 1 is 3. It can be seen with trial 1. Hence, all the parameters with level 2 are more satisfactory, because the level 2 conditions (trial 8) provide no cracks in the cylinder liners. Heating the iron to 900oC causes an austenite structure with about 0.60 to 0.80% dissolved carbon to be developed. Subsequent quenching in the oil being agitated will produce a martensitic structure. The hardness of liners after treatment in old and new process, are respectively in the ranges of Rcokwell 45 to 50 C and Rockwell 48 to 55 C.

4. CONCLUSION

1. The heat treatment time is fund be more significant. The predicted optimum number of cracks with time at level 1 is 3.
2. The selected levels of the process parameters to obtain minimum cracks are given Table -5 above.

With the above conclusion, the new process can produce more number of high quality cylinder liners than the old process in the same shift time. This is mainly because of reduction in heat treating time. The microstructure if liners produced by optimum treatment conditions constitutes combined carbon, retained austenite and martensite. The hardness of liners after heat treatment using new process is in the range of Rockwell 48 to 55 C.

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APPENDIX

The estimated mean of cracks = $\overline{B_1}$

Confidence Interval, CI = $\sqrt{\frac{F_{\alpha;1;v} V_{ep}}{n_e}}$

$$n_e = \frac{\text{Total number of experiments}}{1 + \left[\begin{array}{c}\text{Total degrees of freedom} \\ \text{associated with items used} \\ \text{in the estimate of mean}\end{array}\right]}$$

$F_{\alpha;1;v}$ = F value from standard table at required confidence level (α) at degree of freedom 1 and error degree of freedom (v)

V_{ep} = Variance of error pooled

C11 = ±0.25

The predicted range of cracks

$$2.5 \leq 2.75 \leq 3$$