Study of the Effects of Heat Treatment on the Quality of Mechanical Transmission Half Shaft by the Analytical Hierarchy Process (AHP)

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Abstract

During manufacturing, quality must be maintained, it has always been considered a very important success factor for companies. Producing high quality products while maintaining minimal costs is the mandate of all manufacturing companies. Therefore our study is based on the study of quality defects of Half Shaft part. A Moroccan automobile manufacturer of mechanical transmission parts is considered as a testing ground, the case study is oriented towards the study of induction hardening process of the Half Shaft part. In order to meet customer requirements in terms of part hardness specifications, a heat treatment is applied which subsequently generates depth hardness defects. A classification method based on the Analytical Hierarchy Process (AHP) is applied in order to classify these defects according to specified criteria chosen by experts. It is a decision-making method in the case where there are several criteria. The defects generated in the induction haredening process are depth hardness defects which differ according to the section of the part. In this context, four depth hardness defects will be considered, and three criteria will be chosen in order to applicate the AHP method. The classification of these defects helps to select the crucial defect to eradicate it and subsequently obtain better quality parts.

Key Words :

Quality, Analytical Hierarchy Process (AHP), Hardness defects, Induction Hardening, heat treatment.

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Introduction

Today the Moroccan automotive sector is in continuous progression, automotive manufacturers are under severe competitive pressure due to increased global competition and customer demands. In order to meet this challenge, quality must be maintained. It has been recognized for many years as a key success factor for companies in order to improve their productivity and not lose their competitiveness. Indeed, quality has a fundamental role in production processes, as it guarantees the reliability of products/services according to customer requirements. It is on this basis that our research is directed towards the study of the defects generated during the heat treatment which impacts the quality of the product.

In this article, we will focus on the classification of defects while applying a classification method based on the Analytical Hierarchy Process (AHP). Our case study is oriented towards the study of injection hardening process of mechanical transmission parts (Half Shaft) for a Moroccan automotive industry.

In this context, we considered four defects of depth hardness of the Half Shaft part which differ according to the section of the part, we will classify them according to three criteria.

The article is divided as follows: Section 1 "Literature review" gives an overview on the quality and description of the classification method used. Section 2 "Research Methodology" presents the flowchart of our research. Section 3 "Case Study" describes the application of the AHP method in the classification of Half Shaft part hardness defects and finally a discussion of the results is presented in Section 4.

Objective
Our objective in this research is to classify the hardness defects of Half Shaft parts according to their severity. This classification allows us to analyze the defects in order of importance and then give importance to the critical defect to resolve it and have a compliant product.

Literature Review
The presented literature is divided into two sections. The first presents the importance of quality to the manufacturing sector. The second offers a description on the AHP method for the classification of hardness defects which subsequently helps in solving manufacturing quality problems.

Quality Overview
Quality has always been considered a key factor in business success. Since the 80s and 90s, philosophies like Total Quality Management (TQM) started in Japan in the early 1980s and Lean Six Sigma Invented by Motorola in 1986, quality control and inspection tools and methodologies have been implemented by many organizations to improve customer satisfaction and at the same time reduce non-quality costs [1].
Deming (1982), in his book "Out of the Crisis", stated that apart from sophisticated business strategies, the most certain path towards growth in an industry is quality endowment through continual improvement [2]. So in order to attract customers and lead to business growth quality must be maintained. It is defined in several ways. The most relevant definition in this article is given by Juran (2017), he defined quality as follows: "Quality means the absence of defects – the absence of errors that require reworking" [2]. Therefore, in order to have a product of good quality, an analysis of the defects is essential, so to ensure an effective analysis, we will start by classification of the defects in order of importance according to several criteria,

AHP Method
The AHP (Analytic Hierarchy Process) method developed in 1980 by Saaty (1980) is a decision-making method. It allows to dissect a problem in a logical way by moving from a higher level to a lower level until you reach a simple comparison for each pair of criteria, then you can go back to the higher level for decision-making. [3] [4]. Generally the hierarchy has three levels; the goal, the criteria, the alternatives (Figure 4). Hierarchy levels describe a system from the lowest level (sets of alternatives), through intermediate levels (sub-criteria and criteria), to the highest level (general object). It is the essence of AHP that human judgments, not just the underlying information, can be used to make the assessments [4].
In order to compare distinct attributes, priority numerical values are assigned to the attributes on a scale of 1 to 9. (Table 1)

Table 1. Saaty scale [3]

Weight or intensity of comparison	Verbal judgment of preference
1	Same importance
3	Moderate importance
5	High significance
7	Very strong importance
9	Extreme importance or absolute importance
2,4,6,8	Used for judgments intermediate to those listed above

The comparison is based on expert opinion, some inconsistencies may occur in the system which can be checked by the consistency rate (CR).
The steps of the AHP method are as follows [3] [5]:

Step 1: Identify the criteria

The fixed criteria must be identified by the decision makers C1, C2, C3, … for the classification of the defects. Then we move on to normalization or standardization this criteria. For default i and criterion j we have:

$$y_{ij}^* = \frac{y_{ij} - \min_{i=1\rightarrow\cdots\cdots N}\{y_{ij}\}}{\max_{i=1\rightarrow\cdots\cdots N}\{y_{ij}\} - \min_{i=1\rightarrow\cdots\cdots N}\{y_{ij}\}} \qquad (1)$$

Step 2: Determination of the comparison matrix A

In the hierarchical analysis process, the relative importance of criterion i with respect to criterion j is determined using the Saaty scale and is assigned to the (i,j)th position of the comparison matrix by pairs.

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \; with \; a_{ij} > 0 \, , \; a_{ii} = 1 \; , \; a_{ji} = 1/a_{ij} \qquad (2)$$

Step 3: Calculate the AHP weights of the different criteria

The weights of the criteria are the eigenvector of the highest eigenvalue of the matrix A

Step 4: Checking the consistency of our approach

$$CR = \frac{CI}{RI} \quad (3) \qquad ; \qquad CI = \frac{\lambda_{max} - n}{n - 1} \quad (4) \qquad \text{with } \lambda_{max} \text{ eigenvalue}$$

n: number of criteria

RI: random consistency index = predefined value (depends on the size of the matrix [3])

The value of CR must be less than 0.1 to conclude that the pairwise comparison judgments are consistent.

Step 5: Calculate a weighted score of each defect in order to classify them

$$S_i = \sum_{j=1}^{n} \omega_j y_{ij}^* = \omega_1 y_{i1}^* + \omega_2 y_{i2}^* + \cdots + \omega_n y_{in}^* \qquad (5)$$

Research Methodology

The research methodology is illustrated as follows:

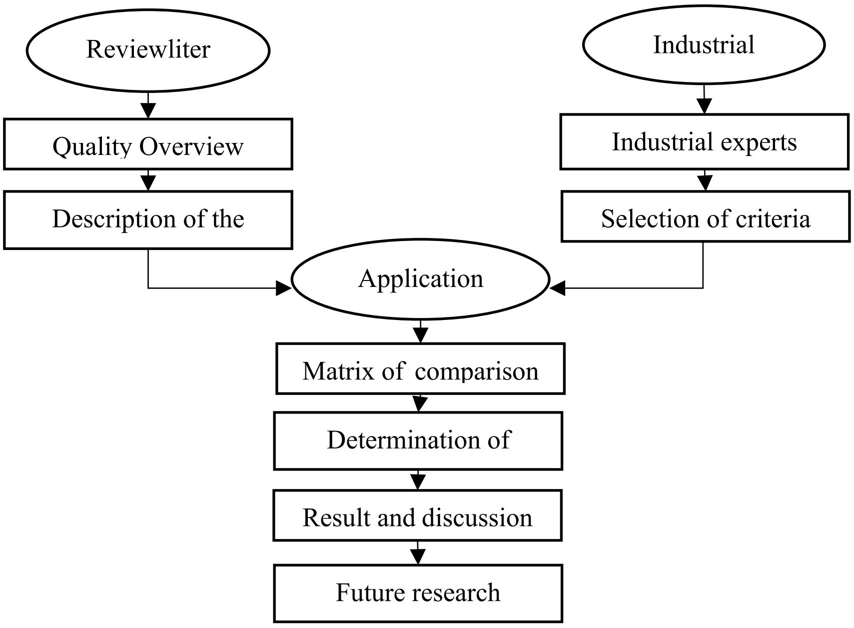

Figure1. Study flowchart

Case Study

Collection Data

This article applies the AHP method for the classification of hardness defects via a real automotive company manufacturing mechanical transmission parts (Half Shaft) in Morocco.
The induction haredening process involves very critical hardness defects which have a serious impact on the vehicle after running because the cracks cannot be seen visually during production, hence the need to calculate the hardness in the laboratory at varying depths and to different sections of the part according to the customer specification (Table 3).

We considered 4 hardness defects according to the section (Figure 2):

A: depth to HRc 50

B: depth to HRc 50

C: depth to HRc 50

F: no hardening permitted

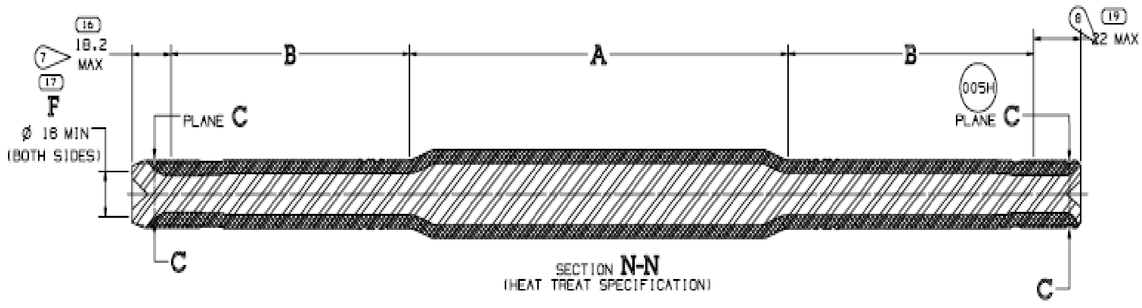

Figure 2. Half Half

Measurements are made in the laboratory one piece every 4 hours to calculate the hardness of each section. The part is cut (Figure 3) and a chemical attack is applied which affects the color of the part and then the hardness of each location is measured at 50HRc

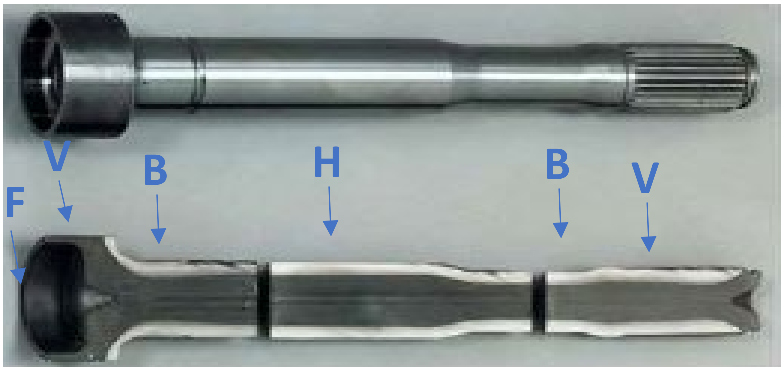

Figure 3. Half Shaft part cut in the laboratory

Each section must respect measurements required by the customer (Table 2)

Table 2. Customer Specifications

Area	Customer specifications
Sec A – Depth to HRC 50	Between 4.0 and 5.3
Sec B – Depth to HRC 50	Between 4.0 and 5.0
Sec C – Depth to HRC 50	0.5 Mins
Sec F No hardening permitted	Ø16 Min

Further by brainstorming with decision makers such as machine operators, maintenance experts, production managers, technical and financial experts, etc. ; we concluded that the calcification of the Half Shaft part hardness defects depends on three criteria:

C1: Occurrence

C2: Detection

C3: Criticality

The Analytical Hierarchy Process (AHP) for classifying hardness defects of Half Shaft part is shown in Figure 4:

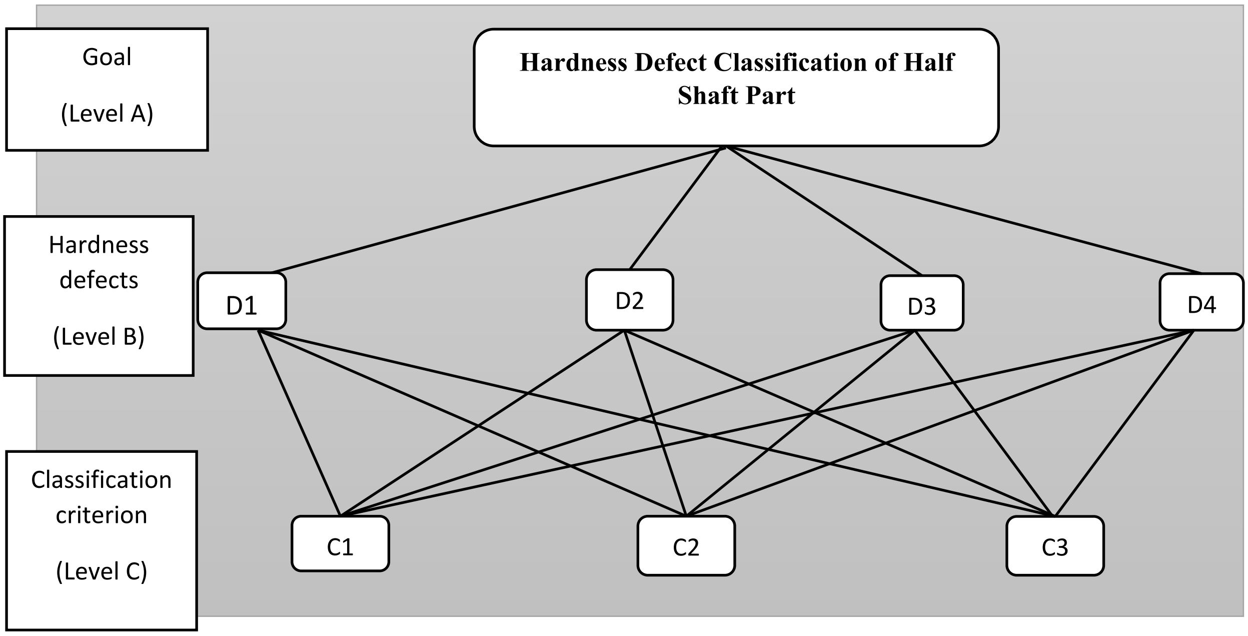

Figure 4. The Hierarchical Structure for the Selection of Half Shaft Part Hardness Defects [4]

On the basis of a history of 1 year, the occurrence of each defect (C1) was calculated. Then a study of 72 samples is made for the calculation of the two remaining criteria C2 and C3 of each defect. Table 3 presents the achieved results:

Table3. Initial data

Defaults	Criteria		
	C1 Occurrence	C2 detection	C3 Criticality
HAS	30	2	5
B	11	2	5
VS	15	5	2
F	3	3	1

4.2. Weight calculation based on AHP

$(\omega_1;\ \omega_2;\ \omega_3)$ represent the weight values of C1; C2; C3 respectively with $\sum_i \omega_i = 1$

By a weighted vote we obtain the following comparison matrix:

$$A = \begin{pmatrix} 1 & 5 & 7 \\ 0{,}2 & 1 & 4 \\ 0{,}14 & 0{,}25 & 1 \end{pmatrix} \quad (6)$$

From equations (3) and (4) the coherence ratio CR = 0.094 =>CR < 0.1 which confirms the consistency of the judgments at the level of the matrix.

The calculation of the eigenvalues as well as the eigenvector associated with the largest eigenvalue made it possible to identify the following coefficients for the three criteria: (Table 4)

Table 4. Weight of criteria

Criteria	Coefficient
C1	0.73

C2	0.20
C3	0.07

4.3. Calculation of the weighted score

From equation (5) and the data in Tables 3 and 4, we obtain the optimum weight of each hardness defect (Table 5):

Table 5. Optimal weight and classification of defects

Default	Optimal weight	Class
A	0.80	1
B	0.29	3
C	0.53	2
F	0.066	4

Results and Discussion

After applying the AHP method of classification the primary defect is A with a score of 80% followed by defect C with a score of 53% then defect B with a severity of 29% and finally defect F with a low importance of 6.6%.

Thus, an analysis of the range of defect scores shows a very wide range of 73.4% since the maximum score is 80% while the minimum score is 6.6%. This allows us to subsequently give great importance to the relevant defect in the problem-solving phase without wasting time in resolving less important defects.

Conclusion

In this article, a hardness defect classification method was applied, the AHP (Analytical Hierarchy Process) method; this method mainly comprises five steps: (1) identification of the criteria, (2) determination of the comparison matrix, (3) calculation of the AHP weights of the different criteria, (4) verification of the consistency of our approach, (5) calculation a weighted score of each defect in order to rank them.

A hardness defect classification case study has been provided to illustrate the method and test its effectiveness. The results show that the proposed method helps to make effective classification decisions when there is more than one criterion.

As future research we will base on the problem solving phase, that generates the critical hardness defect in order to have a good quality product and satisfy the customer.

References

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