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INSTRUMENTS OF QUALITY ASSURANCE TO STRUCTURAL MATERIALS

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ABSTRACT: *The article presents results of own research with usage of quality assurance instruments to structural materials. In this research was determined the application frequency of selected instruments. There was presented the usage possibility of quality adjusting function and objective function (including fatigue properties) in ensuring adequate quality of structural materials.*
KEYWORDS: *quality, QFD, objective function, fatigue*

INTRODUCTION

The definition of quality contained in ISO 9001 standard terminology treats quality as the degree to which a set of inherent characteristics fulfills requirements [1]. By property, differentiating feature is understood. Differentiating product features should not be related only to so-called technical quality, but to all the benefits that the company can offer its customers. In relation to engineering materials, we can assume that quality is the fulfillment of requirements placed by the standards or meeting requirements specified in the acceptance protocol by the client with optimal costs. Quality of engineering materials is related to technical quality, which depends mainly on raw materials and technological process of product manufacturing. Quality of raw materials is determined above all by their original chemical composition and structure. Then properties of raw materials (engineering materials) have impact on technological process. Changes in qualitative properties of manufactured products takes place during technological process, these changes depend on technological parameters and properties (hardness, strength, toughness, fatigue, chemical composition, microstructure) of material used in the process.

When carrying out technological processes (production) they should be earlier planed with taking into account:

- *objectives connected with quality and requirements connected with product (e.g. mechanical properties or other specification set by the customer),*
- *documentation (performance criteria, procedures, instructions and standards),*
- *necessary resources (qualification of contractors, appropriate equipment),*
- *required actions connected with verification, validation, monitoring, control and specialist research for the product or material and product acceptance criteria,*
- *records which will provide evidence that realization process and product meet assumed requirements.*

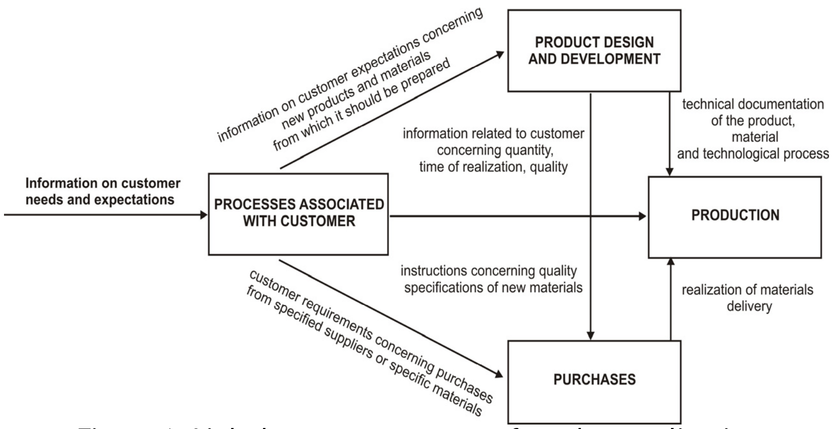

Figure 1. Links between processes of product realization

Figure 1 shows links between processes associated with realization of the product.

QUALITY ASSURANCE DURING DESIGNING AND MANUFACTURING

New requirements placed in front of products, and thus in front of materials from which they are made caused development of methods and instruments of quality assurance. Depending on product's purpose the process of its production is burdened with the need to implement quality *assurance systems, recording and data analysis, and moreover with the process of continuous improvement based on the Deming cycle (PDCA-Plan, Do, Check, Act) [2].*

The processing of processing raw materials into a product is called the process of manufacture or the manufacturing process, which involves making a product, using the resources in terms of materials, energy, capital and human resources. The selection of material for products must be made on basis of multi-criteria optimization, including those based on materials properties (relative cost, density, elastic modulus, strength, ductility, fatigue index, thermal conductivity, diffusivity, specific heat, melting point, resistance to thermal shocks, wear index, corrosion index and others). Generalized function of objective can be used [3], as well as Ashby's material selection charts [4].

In order to ensure adequate quality to materials, products and to solve problems effectively, knowledge about the process or object, which the problem concerns, is required. Table 1 shows the elements of knowledge that are needed to guarantee high level of quality to materials and objects made from these materials. In engineering practice the problem of poor quality of the product can not be limited to one stage of its life cycle. Defects of finished product detected in the customer or non-compliances identified in the company may have its origin in ill-defined assumptions and poorly organized production system. Occurrence of non-compliances can be intensified by the use of inappropriate materials (unsuitable structure, chemical composition, mechanical properties, etc.), inadequate treatment or by incompetent assembly. However, in practice we deal with the case where all quality determinants to material and technology meet customer's expectations but the price of the product is a discriminatory factor on the market. Product, apart from meeting customer's technical requirements, must be competitive. Organization of production system is responsible for this factor.

Table 1. Elements of knowledge necessary to ensure quality to objects produced of engineering materials

Stages of production / Elements of knowledge	Product Design	Manufacturing process
Requirements regarding product and process	Knowledge of requirements concerning: - use of the product, operating conditions, reliability, - staff qualifications, - qualitative capability of machines, - equipment and production methods.	Knowledge of technological requirements regarding product and material of which it is made.
State of the project State of the process	Knowledge about potential critical points in terms of: - materials (structure, chemical composition, stresses concentration,.....), - producibility, - processes qualitative ability - machinery and equipment qualitative ability, - qualifications of employees,	Knowledge about possibilities of occurring incompatibilities during production time, such as reduction in fatigue strength, heterogeneity, segregation, etc.
Possible corrective actions	Knowledge about: - technological procedures which enhance the mechanical properties characteristic, - alternative structural materials, - possibilities of changes in technology, - possibility to change devices.	Knowledge about: - possibilities for improvement of qualitative capability of machines and processes.

Subject literature [5÷8] identifies five methods of quality management, as well as seven traditional, and seven new instruments of quality assurance.

System which ensures required technical parameters needs continuous improvement. The condition for improvement is quantification of the problem (statistical methods, control charts, histograms, Pareto-Lorenz diagram, degree of the risk - FMEA method, qualitative capacity factor) and then proposed solution in descriptive way (new tools). Based on own research, the frequency of usage of methods and instruments which are applied in quality assurance to materials and raw materials used in the manufacture process of products is presented in Figure 2.

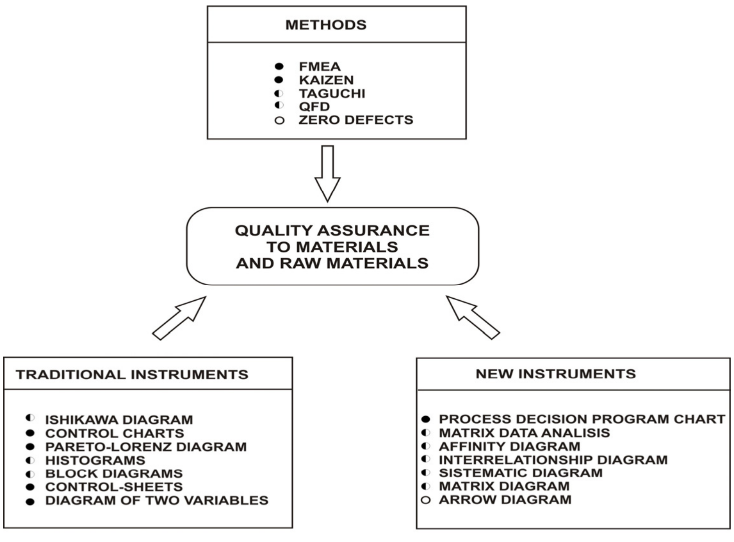

Figure 2. Methods and instruments of quality assurance to structural materials and products

APPLICATION OF QFD METHOD IN IMPROVING PRODUCTS QUALITY MADE OF ENGINEERING MATERIALS

QFD method is a way to translate information from the customer on technical and technological parameters concerning material and implemented processes. It aim is to establish technical parameters of the product, parts and then process, where they will be implemented. QFD found application in engineering works in design, preparation and starting production of new products. Figure 3 shows diagram of QFD house of quality.

The main elements of the house of quality from the standpoint of the engineer are following areas:

- *Field III determination of technical parameters of the product.*

Technical parameters must be chosen in the way that they meet user requirements; they must be measurable and realistic, that means they will be possible to obtain at production stage. Technical parameter can have minimal, modal value or maximal value. If analyzed parameter is minimal it means that the lower value the better - user's requirements are met. In case of nominal value there exists some optimum value for parameter, to which you should get as close as it is possible.

- *Field IV determination of relationship between technical parameters and customer requirements.*

Relationship between technical parameters and customer requirements is determined on the basis of functional analysis. It should be noted that certain technical parameters affect the fulfillment of several requirements such as coating should serve protective and aesthetic function.

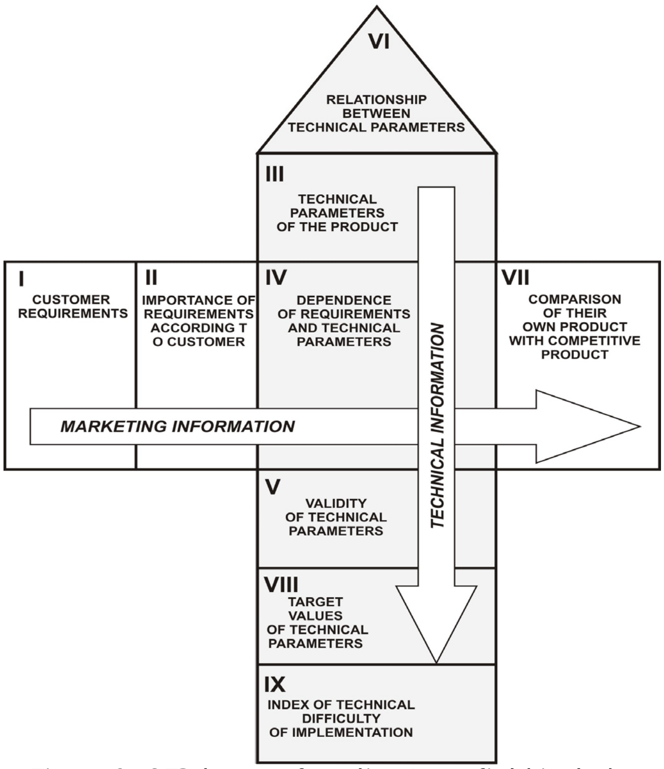

Figure 3. QFD house of quality (gray field includes engineering aspect of QFD analysis

- *Field V assessment of validity of technical parameters.*

By using the numerical scale in order to determine client's requirements the importance of a given technical parameter can be determined. This is the sum of products of consecutive requirements importance coefficients and coefficients of their relation with a given technical parameter (model 1).

$$T_j = \sum_{i=1}^{I} W_i Z_{ij} \qquad (1)$$

If W_i is the validity coefficients of i requirement and Z_{ij} is the coefficient of correlation between i requirement and j technical parameter so validity of j technical parameter is T_j.

- *Field VI identification of significant interactions between technical parameters.*

Technical parameters in many cases interact with each other, which often affect the ability to meet customer requirements. For example, thick electrolytic coating increases corrosion resistance but reduces fatigue strength.

- *Field VII evaluation of competitive products properties.*

Using the assumed scale, for example from 1 to 5, selected technical parameters of material, parts, construction with competitive products parameters can be compared.

- *Field VIII establishment of target technical parameters.*

After completing the fields from I-VII we have a set of information on being designed product (parts). With this information it is possible to establish target values which must be achieved measurable technical parameters, so as to meet customer requirements or increase competitiveness of the product (parts).

- *Field IX establishment of indexes which are the measure of technical and organizational difficulty.*

There are determined indicators which are the measure of technical and organizational difficulties, which occurrence can be expected in achieving target values of technical parameters. The most commonly is used scale from 1 to 5. High value of indicator means that you should expect significant problems and need to pay to a given parameter special attention, through the use of increased scope of control.

Figure 4 shows QFD phases on example of designing the end of car rope as an element assembled in a passenger car.

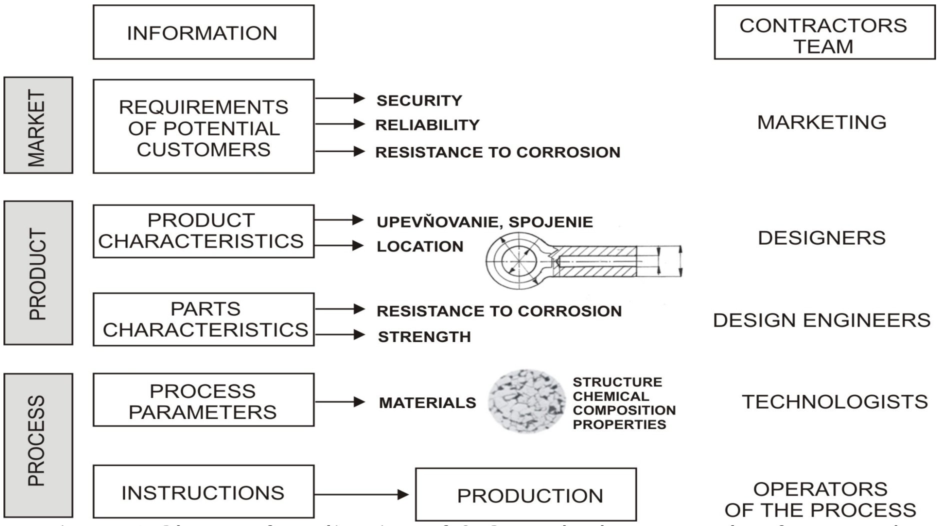

Figure 4. Phases of application of QFD method on example of rope end

USING OBJECTIVE FUNCTION IN QUALITY ASSURANCE

When analyzing the impact of various factors on properties of being designed detail, we encounter difficulties in their evaluation, because they are generally quantities incomparable with each other and uncountable. In this case, analyzed partial characteristics should be reduced to dimensionless form and use method called overall objective function [8].

At the beginning values scope of individual input parameters y_1, y_2, ..., y_n should be transformed into dimensionless selection scale d with values within the interval (0÷1). This scale expresses relationship between input parameters values y_1, y_2, ..., y_n and corresponding with them values of d_1, d_2, ..., d_n. Value of $d_i = 0$ corresponds to such value of input parameter y_i, which is absolutely unacceptable. Value of $d_i = 1$ corresponds to the best value of input parameter y_i, while further its improvement is impossible or inadvisable. Transformation of the input value (dimensional) y into dimensionless d is made according to the following exponential dependence:

$$d_i = \exp[-\exp(-z_i)], \quad (2)$$

where:

$$z_i = b_0 + b_1 \cdot y_i. \quad (3)$$

After conversion and bilateral finding the logarithm of (2) equation there is received:

$$z_i = -\ln(\ln 1/d_i). \quad (4)$$

Coefficients b_0 and b_1 can be determined from equations:

$$z_{i1} = b_0 + b_1 \cdot y_{i1}, \quad (5)$$

$$z_{i2} = b_0 + b_1 \cdot y_{i2}\ , \quad (6)$$

which are determined for two different input values of y_i parameter with given for them appropriate selection values d_i. When solving given system of equations (5) and (6) there are obtained:

$$b_0 = \frac{z_{i1} y_{i2} - z_{i2} y_{i1}}{y_{i2} y_{i1}}, \quad (7)$$

$$b_1 = \frac{z_{i2} - z_{i1}}{y_{i2} - y_{i1}} \quad (8)$$

In described way there are carried out conversions of value of each input parameter y_i into dimensionless scale d_i. Having determined selection values d_i for all input parameters, there is calculated general quality function D (eq. 9) as geometric mean of special partial functions.

$$D = \sqrt[n]{d_1 \quad d_2 \quad \dots \quad d_n} \quad (9)$$

The values of D function belong to the interval 0 ÷ 1.

Objective function was used to ensure optimum selection of material (to provide the best properties) to structural element for automotive industry. To characterize utility there were accepted the following criteria: criterion of corrosion resistance (d_1), criterion concerning mechanical properties - fatigue strength with electrolytic coating (d_2), criterion concerning physical properties of glass (d_3), roughness (d_4) and economic criterion (d_5).

Under tests went products for the automotive industry from SGRJ235 steel covered with nickel and chromium coating. To obtain the fatigue properties of this steel and to explore the influence of *the nickel and chromium coating there were carried out fatigue tests with use of high-frequencies f = 20 kHz beyond conventional limit of 10^7 cycles (Figure 5).*

Based on received results, there were accepted assumptions for each objective function, assessing fatigue limits for two types of coatings: nickel and chrome. The specific objective function (given in Table 2) was also identified.

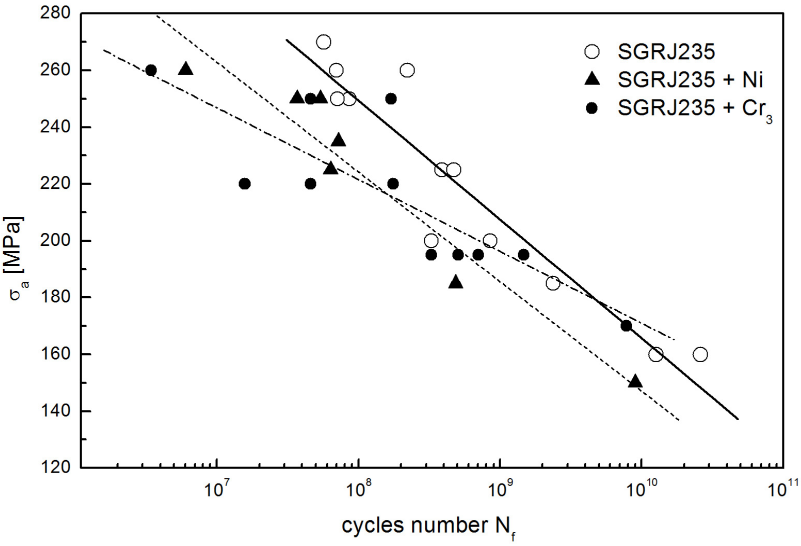

Figure 5. Fatigue strength σ_a = f (N), SGRJ 235, SGRJ 235 + Ni, SGRJ 235 + Cr_3 (research performed at the Department of Materials Engineering, Faculty of Mechanical Engineering, University of Žilina).

Table 2. Calculations results of detailed objective functions concerning fatigue resistance.

Coating type	Parameter b_o	Parameter b_1	Special objective function
SGRJ 235 + Ni	-2.7337	0.0113	d=exp[-exp(2.7337-0.0113·y)]
SGRJ 235 + Cr_3	-2.5677	0.0116	d=exp[-exp(2.5677-0.0116·y)]

After carrying out all detailed calculations which results for detail with nickel coating is shown in Table 3, it is possible to compare obtained results with the results obtained from the detail with chromium coating.

Table 3 . Comparison of string end parameters with nickel and chromium coating.

Partial value	Characterizing parameter	Ni coating	Cr coating
d_1	Corrosion resistance	0.73	0.85
d_2	Fatigue resistance	0.75	0.67
d_3	Gloss	0.71	0.76
d_4	Roughness	0.60	0.61
d_5	Price per 100 kg of product	0.60	0.81
General objective function D		0.67	0.73

In analyzed case it was found that at assumed choice parameters (partial functions) to production should be used the detail with chromium coating.

CONCLUSIONS

In this work was carried out review of research results aiming to answer the question how tools and methods of quality assurance are used in engineering works, in particular in materials engineering. The use of analysis methods of causes and effects of defects (FMEA), quality function development (QFD), Taguchi and Kaizen method of continuous improvement is necessary to improve parameters of engineering materials and products. The most appropriate method is the usage of FMEA method, which gives great possibilities in the evaluation process of improving selected material characteristics as well as manufacturing processes. It is most commonly used method in Polish conditions. QFD method gives large pro-quality effects; however, its implementation in enterprises is much more difficult than FMEA method. Using of generalized objective function enables to obtain by material or product made of this material certain physical and mechanical properties. The research, which was carried out, confirmed effectiveness of use of generalized objective function for choice of suitable electrolytic coating including: physical, mechanical, and also economic factor.

In order to meet the market demands it is necessary to implement system solutions, which in addition to measurements - guarantee of the material in compliance with requirements, would provide optimal conditions of manufacturing systems operation.

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