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UNIVERSITY OF NIŠ

FACULTY OF MECHANICAL ENGINEERING IN NIŠ

THE FIFTH INTERNATIONAL CONFERENCE

“MECHANICAL ENGINEERING IN XXI CENTURY”

- MASING 2020 -

PROCEEDINGS

Niš, December 09-10, 2020

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PREFACE

Six decades of tradition, high standards in the education of generations of students, modernly equipped classrooms, professional teaching and associate staff, their references and recognizability, position the Faculty of Mechanical Engineering, University of Niš, as the leader in the field of engineering sciences and technological sciences, not only on the territory of the Republic of Serbia but also in the wider region of the Western Balkans.

The Proceedings of the 5th International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** appear in the year when the Faculty of Mechanical Engineering, University of Niš, celebrates its the sixtieth anniversary. The Department of Mechanical Engineering of the Faculty of Engineering in Niš was founded on May 18, 1960, and it developed into the Faculty of Mechanical Engineering of the University of Niš in 1971. The Faculty of Mechanical Engineering grew intensely, thus becoming one of the most renowned scientific and educational institutions in the country.

The mission of the Faculty is to organize and conduct academic study programs and to develop and perform scientific and professional work in the field of engineering sciences and technology. Its vision is to be recognizable in the European and global academic environment in the areas of mechanical engineering and engineering management.

More than 90 teachers and associates, around 40 members of non-teaching staff, as well as numerous teachers and associates from other faculties and the industry, are working hard every day to accomplish the mission and vision of the Faculty.

The Faculty of Mechanical Engineering, University of Niš, is accredited in compliance with the Law on Higher Education within the scientific and educational field of engineering sciences and technology. It conducts the academic studies of the first degree – undergraduate studies, the second degree – master academic studies, and the third degree – doctoral studies, within the scientific area of mechanical engineering and engineering management.

The Faculty of Mechanical Engineering is a scientific research institution, in addition to being an educational one. There are 11 international scientific research projects within the framework of HORIZON 2020, ERASMUS, CEEPUS and DAAD programs. The participation of teachers and associates from the Faculty in these projects is of utmost importance for their educational and research work and their further career.

The 5th International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** represents a forum for the presentation of latest results, basic and developmental research and application within the topics of:

- Energetics, energy efficiency and process engineering,
- Mechanical design, development and engineering
- Mechatronics and control
- Production and information technologies
- Traffic engineering, transport, and logistics
- Theoretical and applied mechanics and mathematics
- Challenges of the engineering profession in modern industry and
- Engineering management.

The MASING 2020 Conference has attracted just over 200 participants from 14 countries, with over 80 papers. The papers present the research results within the scientific work financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, as well as the research results within international projects.

The main goal of the Conference is to bring together researchers from scientific and industrial institutions so that they can present and communicate their newest results, create personal contacts, promote research within the area of mechanical engineering, and stimulate the exchange of results and ideas within the fields encompassed by the Conference.

As Dean of the Faculty of Mechanical Engineering in Niš, I am honored to greet all participants of the Conference and wish them very successful work..

Dean of the Faculty of Mechanical Engineering,
University of Niš

Prof. dr Nenad T. Pavlović

Niš, December 2020

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Transient Finite Element Analysis (FEA) in Material Selection Process: Introduction

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Abstract— **The suitable material selection for a particular mechanical part or assembly is one of the most important tasks in the product development process. Due to the presence of a vast number of materials with diverse characteristics, the material selection process is a complicated and time-consuming task. There is a need for a systematic and efficient approach to choose the most suitable material type to fulfill the part's requirements and proper use inside the process in which it obtains. Given the function that sub-assembly has inside the production process, the heat distribution will be the most crucial factor in the material selection process. To minimize the risks such as component failure, modeling, and analysis tools such as finite element analysis (FEA) are essential for evaluating material performances non-destructively at the operating temperatures and work conditions. FEA can determine the heat distribution and other relevant mechanical properties necessary for the material selection process. Specifically, this paper introduces the material selection for the tool ("cleaner") responsible for the preparation of the valve application area on the inner tube profile, by transient FEA analysis obtained in Ansys Workbench.**

Keywords— **Material selection process, finite element analysis (FEA), transient analysis, inner tube profile, valve.**

I. Introduction

Engineering includes designing, manufacturing, and maintaining products, systems, services, and structures [1]. Early design decisions can have a very significant impact on the product's sustainability and application. One of these decisions regards the material selection process.

Material selection plays a vital role in process of mechanical and structural design [2]. The material selection process is often a complicated task due to the fact that nowadays the vast numbers of material types are present. Also, the diversity between the same material categories is substantial. Some properties could be good and in compliance with the set requirements, but some of them are not applicable [3]. Those important characteristics of materials are strength, durability, flexibility, weight, resistance to heat and corrosion, ability to cast, weld or harden their machinability, electrical conductivity, etc.

As a result, the understanding of material properties and their behaviour under working conditions is preferable. Given to this and the knowledge of the product's final characteristics and its use, the material selection process needs a systematic and thorough approach.

In order to make a proper decision and shorten the time necessary to obtain the material selection process, some convenient methods could be applied. The complexity of those methods will depend on the number of confronted criteria. Those methods could be [3]: Ashby plots; multi-criteria decision-making (MCDM) approaches and related techniques; fuzzy logic and soft computing-based approaches, etc.

Opposite from the analytical process, the experimental process could also be applied to the material selection process. The experimental process could be obtained virtually or for real.

Nowadays, as a part of the design process, virtual product modelling and manufacturing presented as proper simulations are mandatory. Advantages are numerous and widely spread through all product development phases.

One of the tools used for virtual experiments is Ansys Workbench. This tool represents the finite element method (FEM) which is a numerical procedure used for the analysis of continua and structures. In most cases, the problem which is being analysed is too complicated to be acceptably solved through classical analytical methods [4]. The problem may concern heat conduction, stress analysis, or many others. The finite element (FE) procedures create many simultaneous algebraic equations, which are generated and solved using a digital computer.

Finite element analysis (FEA) was quickly recognized and accepted as a general method of numerical approximation for all physical problems that can be used for solving structural mechanical problems [4]. At present, FEA is used for problems such as fluid flow, electric and magnetic fields, heat transfer, lubrication, etc.

This paper introduces the applicability of FEA transient thermal analysis via virtual experiment obtained in Ansys Workbench for tracking a heat distribution through the structure of the tool ("cleaner") responsible for the preparation of the area for valve placement on the inner tube profile regarding the material selection problem.

For the proper valve application on the inner tube profile in the assembly stage of its production, the valve area must be correctly prepared. This means that by applying the heated tool ("cleaner") on the surface of the inner tube the outer isolation is being melted, thus the surface becomes clean and preheated. There must be no marks of isolation left as well as the valve area has the proper temperature so that in the next step the valve could be correctly applied.

Preheating the valve area helps in making an adhesive bond between the valve and inner tube profile. As a result, locally and for a moment the vulcanisation process begins.

Otherwise, improper cleaning and insufficient preheating could lead to valve detachment from the inner tube, as well as the occurrence of the air gaps after the vulcanisation process. This means that the inner tube is most luckily going to cause critical failure during exploitation.

Apart from the perfect working surface of the "cleaner" and parallel position between the tool and inner tube profile, the tool must be heated evenly.

In order to see how material, distribute heat from the heater through the "cleaner" transient analysis must be introduced.

Transient analysis can be thermal or structural. A transient analysis, by definition, involves loads that are in a function of time. A transient thermal analysis follows basically the same procedures as a steady-state thermal analysis. The main difference is that most applied loads in a transient analysis are functions of time. That means that transient analysis can show how the heat is distributed through the "cleaner's" body and working surface, and how the heat transcends to the inner tube profile.

II. Literature Review

Material selection is an important problem attracting the theoretical and practical interest of researchers.

Since the material selection process is a crucial step in the design process [5], but also a time-consuming process, methods have been developed to help the designers. Generally, for material selection methods it is essential to have a unique bond between theoretical knowledge and practical experience [3].

Most of the material selection processes include a couple of stages: initial screening, development and comparison of alternatives, and determining the best solution [3, 6, 7]. Furthermore, the systematic study of material selection falls within the classical – analytical optimization techniques (i.e. property limits, geometric restrictions, material indexes, cost, cost-performance relation, etc.) [3, 8].

MCDM methods include multi-objective optimization and multi-attribute decision-making, thus the MCDM methods are used in the material selection process. Many researchers have applied this methodology in various material selection problems (i.e. mechanical or electrical products, medicine, biology, civil engineering, etc).

Opposite from MCDM methods, researchers have also used fuzzy logic approaches. The methods based on fuzzy logic have the capability to deal with the complexity and uncertainty of real-world problems in material selection [3].

Irrelevant to the material selection method or approach, the main goal is to make the right materials choice meeting product requirements, such as weight savings, higher product performance, and cost reduction [9].

Finite element analysis can be used to determine the behaviour of materials chosen for the selected product. Depending on the product's requirements or some of its characteristics the type of analysis will vary.

Ansys Workbench as one of the FEA programs offers numerous possible analyses such as static or dynamic analysis, transient (both thermal and static), thermal, electric, thermal-electric, etc.

Giving the specificity and complexity of the problem (heat distribution), there are plenty of researches done regarding the transient thermal finite element analysis. Heat transfer problems are complex in terms of material characteristics which may be time/temperature-dependent [10]. Consequently, heat transfer behaviours, heat convection, and radiation lead to nonlinear characteristics of transient heat distribution problems [10, 11, 12, 13], thus the traditional FEM-based solution method is computationally expensive. In this case, proper approximations methods are advised.

III. Case Study – Material Selection Process for the "Cleaner"

The process of building inner tubes consists of a couple of phases: preparation of the rubber mixture and creating an inner tube profile, assembly of the inner tube profile by performing a butt weld from both sides of the tube, and proper placement of the valve on top of the inner tube profile; properly prepared inner tube profile continues on the curing where the inner tube gets its final process obtained.

Every phase is crucial for the products' proper and safe usage. Every inner tube with flaws, imperfections, and defects is being declared as scrap and immediately discarded.

Since a couple of phases in the inner tube building process occurs separately, they could also be observed divided. The phase which regards this paper's research is the second phase, the assembly phase.

As previously mentioned, this phase has two sub-phases, butt weld joint, and valve placement. Both processes are obtained on the same machine, simultaneously, but with different tools.

The so-called "upper operations" are responsible for the proper valve placement on the inner tube profile (Figure 1).

The process of placing a valve has three steps. Each of these steps must be performed perfectly to avoid the possibility of flaws occurrences. The first step presents the creation of a hole on the upper side of the profile so the compressed air can flow through the valve into the tube. After making a hole, the whole place around it must be cleaned. A clean surface enables the best conditions for the inner tube and valve cohesion. The surface around the hole is being cleaned by the tool which is called the "cleaner".

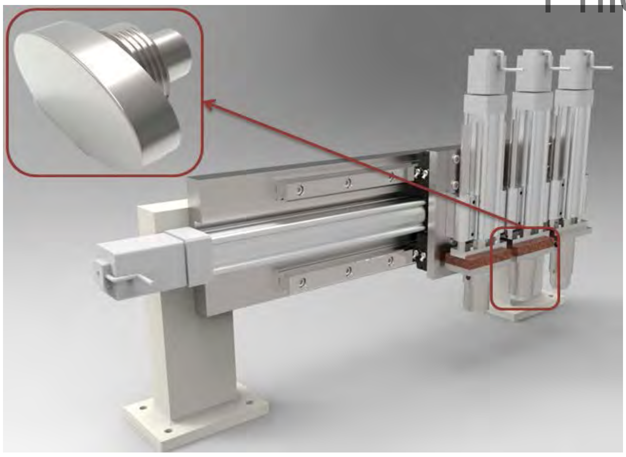

Fig. 1 The assembly responsible for the valve placement on the inner tube profile

The “cleaner” has the exact bottom geometry of the valve and it cleans only the area in which the valve is being applied. Since the cleaner is pre-heated, the outer isolation on the inner tube profile melts, the inner tube profile generates enough heat and it more easily makes a connection with the valve. The final step is to properly place the valve above the hole and over the prepared surface.

“Cleaner” is made of steel and it is screwed into its carrying construction. This construction has two functions: to carry the cleaner and to heat it. The proper heater is also attached around the carrying construction and it conducts a defined amount of heat that passes through it to the working surface (bottom surface) of the “cleaner”.

In case that the “cleaner” is not properly mounted into its carrier or that the surface of the cleaner is polluted or imperfect (scratched, bent, etc.) the uniform heat distribution will not be present. Apart from this, the quality of the material from which the cleaner is manufactured has an important role as well. Inadequate material can cause the same effects even on the perfect surface of the cleaner.

The occurrence of the serial flaws (plats and air bubbles, detachment of the valves) indicated that the process is not stable and that there is a problem in the assembly phase.

A thermal inspection of the “cleaner” was performed using the “FLIR C3” compact industrial thermal camera to track the heat distribution during the machine preparation, as well as during the working process. The results of the thermal inspection are presented in Figure 2.

Figure 3 represents the illustration of the working surface of the tool (“cleaner”) in the position during the thermal inspection process. This illustration also shows the working surface demands in its need of surface purity and geometrical correctness.

By observing Figure 2, it is clear, that the heat distribution on the working surface of the tool (“cleaner”) is not evenly distributed. The centre of the tool is almost at the maximal – set temperature of the heater with a value of 173.8°C (red circle on the centre of the working surface presented on the Figure 2), but the rim area of the surface is approximately evenly distributed with a value of 74.8°C (circle indicator of thermal camera on the Figure 2).

This occurrence could be explained with the process working characteristics in which the “cleaner” is getting colder by transferring the temperature on the inner tube profile, as well as the heat emission in the surroundings.

On the other hand, the consistency of the tool structure and thermal characteristics of the material could also be observed.

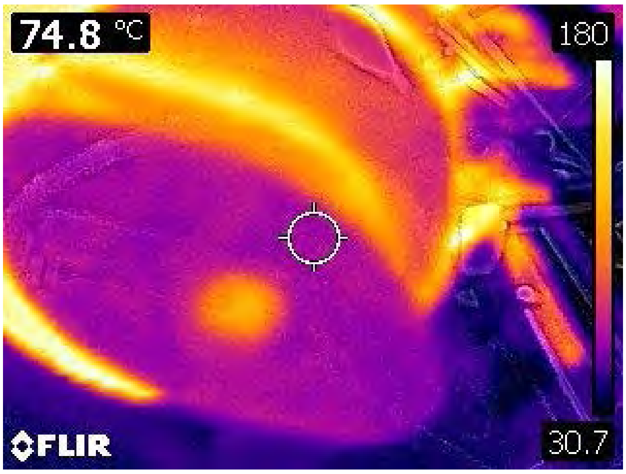

Fig. 1 Thermal camera inspection of the “cleaner” under working conditions

The main idea is to check which type of steel was used for the “cleaner” manufacturing and to try some other types of steel. Since the production process is “unstoppable,” a quick and reliable solution must be applied.

Fig. 3 The working surface of the “cleaner”

In order not to raise the cost and the time required for solving this problem. Tests with new “cleaners” manufactured from new types of materials were not possible. Having that in mind, the decision was made to do a transient thermal finite element analysis and see how different types of material react in the same production conditions.

But first, what we wanted to see is how the present material from which the tool was manufactured acts under the production conditions inside the virtual experiment, transient thermal finite element analysis, in the Ansys Workbench. This way we could have a clearer picture of the thermal processes inside the tool structure; observe the heat distribution from the heater, through the tool, to its working surface responsible for the cleaning process, and make comparison with the results gathered by the real thermal inspection obtained on the assembly machine in the production shop.

The expected results are to see whether the type or structure of material needs to be modified; the construction of the tool ("cleaner") must be redesigned or the type and construction of the heater could also be modified.

A. The Material Selection Process

For this paper's research, the chosen material is by JUS standard Č.1530 which matches the current SRPS EN 10083-2/3 with material reference C45E, steel for annealing, quenching, tempering, and normalizing.

The main reason for selecting this type of material for the FEA analysis is the current material selection of the manufactured tools which are embedded in the production process, as well as the previous experience with the specific material.

Also, the reason for this material selection is to see how tools ("cleaners") with present material behave under working conditions virtually, inside transient thermal finite element analysis.

B. Transient Thermal Finite Element Analysis

As previously mentioned, transient thermal analysis is basically thermal analysis with the addition of time reference. Every FEA analysis regardless of the software has the same principles which must be obtained to gather the desired results.

Those principles involve respectively: material selection (engineering data), the geometrical definition of a solid model, mesh generation, element properties, boundaries, and loads the application and desired outputs (specifically for transient thermal analysis: temperature, total heat flux, directional heat flux, etc.).

After all steps are fulfilled a set of simultaneous linear algebraic equations are being solved in the software background. Output interpretation programs, also referred to as post-processors, will assist the analyst to sort outputs and display them in graphical form.

Respectively to the material selection (steel C45E), the proper inputs are performed regarding the material density, isotropic thermal conductivity, and specific heat capacity [14]. All mentioned values can be found as material properties in textbooks and practicums.

After the material is defined and engineering data imported, the geometry model needs to be built or imported in the design modeller (Figure 1 and 3). Then the model (continuum or structure) must be divided into finite elements. This means that a proper mesh must be generated (Figure 4). This way appropriate type, size, and quantity of elements, as well as their quality, are determined.

Choosing the appropriate type of the element will be determined by the expected response of the model and therefore the accomplishment of the objectives of the analysis [4, 15]. A wide variety of different types is offered by FEA and they can be categorized by family, order and topology.

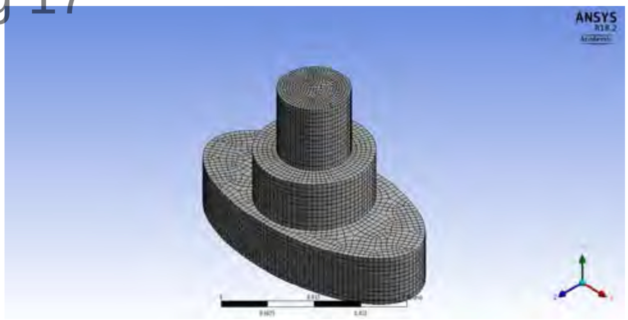

Fig. 4 Mesh generation of the tool structure

One of the crucial steps is to apply loads and define boundaries that represent real working product's conditions (Figure 5).

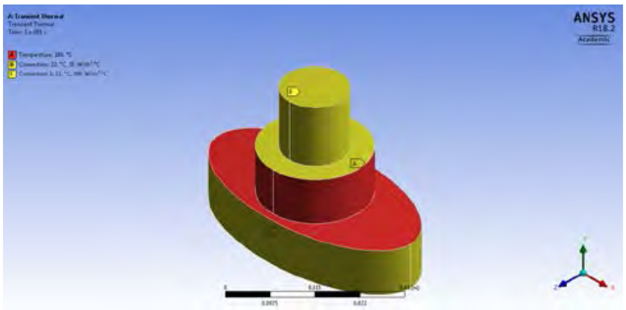

Fig. 5 Loads and boundaries definition

The red area in Figure 5 represents the heating of the "cleaner". The working temperature of the "cleaner" is 180°C which is applied to the model by temperature feature.

The surface above the heated area is placed inside the carrier construction of the tool and it is not in direct contact with the heater, so convection is applied.

The same principle is applied for the surface bellow the heated area, due to the presence of the environment and the contact with the inner tube profile while obtaining the cleaning process.

Finally, the desired output is selected, the heat distribution – temperature analysis.

The mathematical model is created and solved by software and results are shown graphically (Figure 6 and 7).

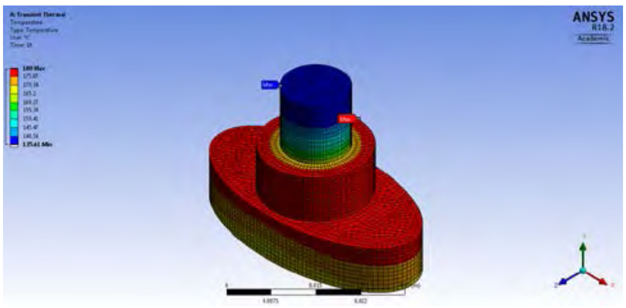

Fig. 6 Results of the analysis

With this research, we wanted to determine the flow of the heat distribution through the tool ("cleaner"). Because of the all mentioned problems regarding the concrete part of the production process (uneven heat distribution on the working surface of the tool) which could lead to unwanted appearances (flaws and imperfections of the inner tube profiles).

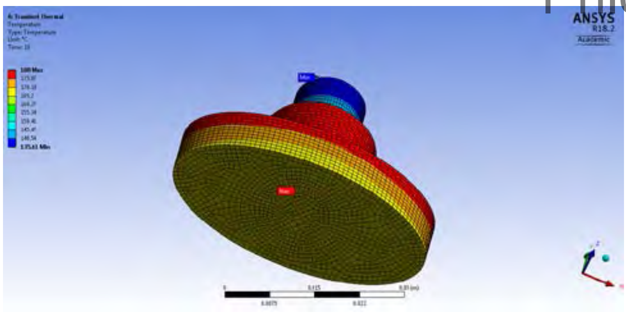

Fig. 7 Results of the analysis focusing the working surface of the tool ("cleaner")

This way, through the set virtual experiment, we wanted to better understand what is happening inside the tool structure and the results that we managed by the transient thermal FEA analysis were satisfying.

The working surface of the tool ("cleaner") is getting heated to the production process demanded temperature with the remark that the working surface is getting colder by transferring heat to the inner tube profile during the cleaning process.

Heat distribution through the tool structure during the preheating stage is rather even (Figure 7). At the end of the preheating process working surface of the tool ("cleaner") is properly heated (Figure 8).

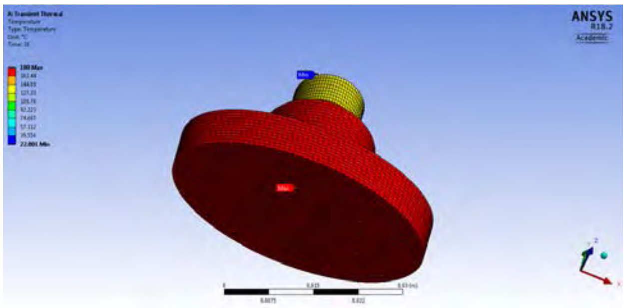

Fig. 8 Results of the analysis focusing the working surface of the tool ("cleaner") at the end of the heating process

However, the heater has a frequent regulation and it is set in an on-off position, depending on the temperature value. Also, while maintaining the cleaning process, the heat is being transferred to the inner tube profile (isolation melting and profile preheating). Thus, in time, the tool loses some amount of heat and needs to recover it by applying it from the heater.

The results of the analysis have shown a good possibility of the applicability of the experiment and the conclusion is that the heat distribution could be tracked this way. Consequently, transient thermal FEA analysis could be applied in order to compare how different materials distribute the heat during the preheating process as well as under the working conditions. This analysis could be applied in the verification of the material selection process.

In order to solve the problem of the thermal inspection, it is proposed to check the heating source (heater), as well as the connections of the heater-carrying construction and carrying construction-tool ("cleaner").

IV. Conclusions

The most present main goal of material selection is to minimize the cost while meeting product designed performances. Reality often presents limitations, and the utilitarian factor must be taken into consideration. The cost of the ideal material, depending on the shape, size, and composition, may be prohibitive, and the demands, the commonality of frequently utilized and know items, its characteristics, and even the region of the market dictate its availability.

Apart from cost reduction and time reduction in the product development process, the power of finite element analysis (FEA) resides in its versatility. This versatility is contained within a single computer program.

FEA can be applied to a number of physical problems and the models analysed can have arbitrary shapes, loads, and boundaries. Input data controls the selection of problems, type, geometry, boundary conditions, etc. Another advantage of FEA is the close physical resemblance between the finite element method (FEM) model and the actual structure [4]. This means that the model is not simply an abstraction.

However, the FEA has disadvantages, too. More complex analysis demand high computer performances and therefore processing time increase dramatically. This could be caused by formation of the model at the beginning of the FEA process [4]. In order to maximize the accuracy and to minimize the geometric approximation of the model, the mesh volume of the model is subdivided into a large number of very small elements. Thus the mathematical model becomes bigger as well.

The main focus of this paper was to set a virtual experiment that realistically reproduces the preparation of the subassembly of the "upper operations" responsible for the valve placement.

The observed process refers to the preparation of the machine, specifically on the process of reaching the set temperature of the tool. This way we were observing the heat distribution through the structure of the tool ("cleaner"), from the heat source (heater) to the tool's working surface. Besides, this experiment also includes heat losses which enhance the quality of the analysis.

For this experiment's purposes only one material has been used, the C45E steel. This material is used for manufacturing the tool ("cleaner") which operates on the machine. This way, we got a vivid picture of how the heat is being distributed through the structure of the tool.

For future endeavours, we are planning to obtain a more profound analysis based on the multi-criteria decision-making (MCDM) methodology. This kind of approach would be appropriate to select the most suitable material for the tool ("cleaner").

The MCDM provides an easy way to observe a wide range of possible alternative solutions (different types of materials) in comparison with multiple confronting criteria (material properties, cost, etc.).

The results of such a kind of analysis would not only be the one best possible alternative solution but also the ranking of all included materials on which further analysis could be applied.

As previously mentioned, the applicability of transient thermal FEA analysis as the verification of the selected materials, from which the tool is being manufactured and the heat distribution criterion is crucial.

The simultaneous analysis of the behaviour of the couple of different materials chosen by a MCDM methodology could show which material is best in transferring heat from the source to the desired surface. That means that we need to overdo the same virtual experiment (as described in this paper) and maintain the comparative analysis on how those proposed materials react under the same working conditions.

The result of the comparative analysis of the transient thermal FEA analysis would be which chosen material best suits the described problem.

The material selected would be proposed for the tool manufacturing and subjected to real experiments inside the production process and real working conditions.

Only when all those described steps are done, the material selection process verified by FEA analysis could be completed and confirmed.

If the results are insufficient, partial changes (the working surface of the tool cannot be changed because of the structure of the valve) as geometrical optimisation and modification of the tool (“cleaner”) could be performed in term of improvement of the tool’s heat characteristics and maximal exploitation of the heater.

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