An experience in integrated knowledge about Manufacturing Technologies for Students of the Grades of Industrial Engineering

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ABSTRACT

In the development of the specific skills in the field of industrial engineering, the transversality of the contents of each area of knowledge must be considered. This paper shows how the integration of the contents of different areas (such as materials, manufacturing, design, etc.) is performed in order to allow students to enhance their transversal skills. For this, a specific product is proposed as "learning object". The analysis, to be made by the students, includes all the aspects regarding technical and economic feasibility, and manufacturing optimization of the product. The article also shows the analysis of the work environment and methodology established by an interdisciplinary group of university teachers from different areas: materials, manufacturing and design who have contributed with their knowledge in the specific problem.

Keywords: Interdisciplinarity; Industrial Engineering; Manufacturing Technology Teaching.

1. Introduction

Nowadays, engineering, broadly speaking, and, particularly, extensive research activities cannot be conceived and projected without a multidisciplinary approach in which different areas of expertise are integrated. Education at universities should not escape from integration as a key concept since departments of human resources of the companies recognize the integrated education as an added value in the curriculum vitae of the applicants [1, 2].

Nonetheless, in the context of higher education institutions, the development of lecturing of science and technology in the industrial framework has been traditionally treated as a set of independent disciplines in which the departments, sometimes, fight for finding their working scope. The same skills to be developed by the students are treated by different areas of expertise and, consequently, different scopes, different universities or simply because of pure availability needs of lecturers [3, 4].

Coordination between teachers of different subjects is a key milestone in teaching of the manufacturing technologies. This fact allows us to improve the educational programs of the grades of industrial engineering in the matters of manufacturing. The main aim is to achieve a better quality in the skills of our students. For that, we perform an integration of the contents as a whole in the programs of the subjects by highlighting the joints between the different matters regarding manufacturing.

The development of skills in manufacturing technologies has, as a key point, the transversal connection between subjects. Design, materials and processes are interconnected by some key factors that must be carefully chosen in order to achieve the specified quality. The contrast between student and professional activities are very high. Students tend to perceive the contents of different subjects as independent topics but, nevertheless, in the professional activity of an engineer the problems are complex and require a global knowledge to be not only solved but also tackled. With regard to manufacturing technologies, the skill to be included in the program of the different subjects can be stated as follows: Knowledge of the relations between materials, shapes, processes and costs. Even though each subject deals with a specific part of the manufacturing problem, our programs account for the connections with other subjects.

This work arises in the framework of a Learning Innovation Project of the University of Valladolid. Among the objectives of the project, some topics such as the statement of the basis of an interdisciplinary workgroup of teacher of different areas of the Industrial Engineering, and the development of transversal skills of the teachers, are included.

In order to carry on the proposed work, the learning objects [5] were defined and each teacher gave the perspective regarding some projects. Those projects deal with very significant forming processes: Traditional processes such as casting, machining and plastic deformation; and nontraditional processes as electrical discharge machining and laser cutting. The project explained in this paper regards with the manufacturing of a rigid overhead catenary with its extrusion die.

2. Methodology and used resources

The techniques mainly used within the workgroup have been brainstorming and case method. This has favored the use of interdisciplinarity in the process of decision-making when looking for a solution. Previously to the beginning of work meetings, the teamwork was propitiated by having research line presentations, visiting laboratories and companies, and organizing specific formation courses (mainly about CAD/CAM/CAE/CAQ tools).

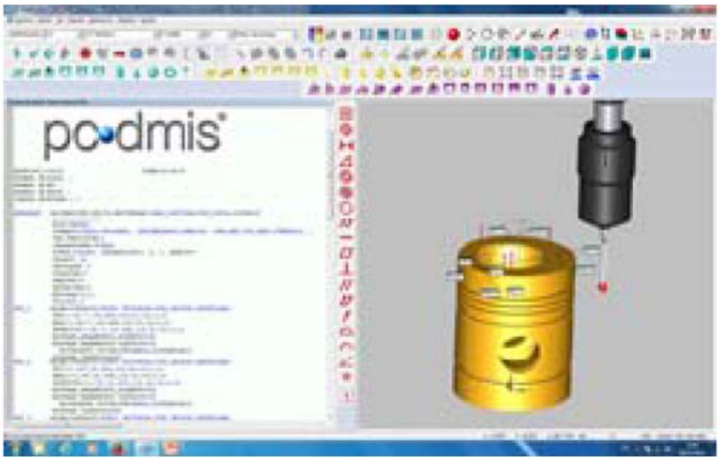

***Figure 1.** Specific formation and tools. Integration of CATIA and PC-DMIS CAD++*

In the following step, the topics to be worked were defined by finding the common and particular elements of the problems. The result was the elaboration of a so called "scope statements" of the different aspects that should be considered for the work with the students.

In the example, a problem involving different areas of the industrial engineering is proposed: the manufacturing of an aluminum alloy rigid overhead catenary that, in contrast to a conventional one, has a better behavior in terms of efficiency and a reduction in the total height of tunnels among other advantages [6]. The main features of the caternary are summarized in Table 1.

Table 1. Characteristics of the rigid overhead caternary

Profile section	2220mm^2
Height	110mm
Length	10−12m
Weight per meter	6.1Kg
Moment of inertia I_{xx}	$338 \cdot 10^4$ mm^4
Moment of inertia I_{yy}	$113.7 \cdot 10^4$ mm^4
Copper equivalent section	1400mm^2
Coefficient of thermal expansion (long.)	$24 \cdot 10^{-6}$
Shear modulus	69000N/mm^2

The profile sustains a copper wire that contacts the pantograph of the train (see Figure 2).

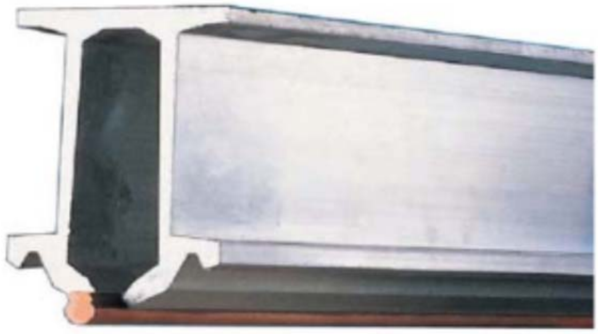

Figure 2. *Rigid overhead catenary. It clamps the copper wire that contacts the pantograph*

The proposed solution will have, in this case, two main objectives: the manufacturing of a rigid overhead catenary and its extrusion die. For each problem, as standard problems, we try to resolve and document all aspects regarding to:

- Denomination of the material (in terms of chemical composition and material treatments)
- Dimensions and tolerances
- Main properties and characteristics
- Planes and 3D models: how to put all the aforementioned information
- Manufacturing problems

3. Learning objects: the case

The integration of the solutions proposed, from the view point of material science and manufacturing processes, is quite significant for the students. It cannot be conceived one without the application of the other. Let us see, promptly, some of the most important points.

2.1 Rigid overhead catenary

Material

The rigid overhead catenary made of an aluminum alloy named 6063 in the UNE norm that is equivalent to the Al Mg 0.5 Si in the ISO denomination. Its chemical composition is plotted in Table 2.

Table 2. Chemical composition of aluminum alloy 6063 (%wt.)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.20–0.60	0.35	0.10	0.10	0.45–0.90	0.10	0.10	0.10	rest

The catenary is formed by hot extrusion at 520°C. At this temperature the alloy also experiments solubilizing. After this process the mechanical characteristics of the catenary are improved by performing an artificial age hardening. Therefore the state of the alloy is designed as a T5 [7].

Manufacturing process

The forming of the profile, that are presented in a sequential way in which forming processes and thermal treatments alternate, is made as follows: Extrusion of the alloy, cut, stretch, age hardening, finishing.

1. Extrusion of the alloy: The aluminum alloy is previously heated up to a temperature in between 400–460°C. Boron nitride (BN) is applied in the surface of the ingot to avoid the adherences to the extrusion chamber. By controlling the pressure of the press, the extrusion speed is controlled. The way out of the material is helped by applying a light traction. The temperature at the out of the press is in between 510–550°C and the cooling is about 50°C/min.
2. Cutting: By using a circular saw the pieces are cut in a length that allows the transportation.

3. Stretching: A stretching bank is used to get rid of the curvature of the profile and, due to the cold work, the material will present enhancement of the strength.
4. Age hardening: This treatment consists in heating at 205°C for one hour followed by a non-forced air cooling.
5. Finishing: Anodizing of the profile is performed. The procedure is an electrochemical one that consists in generating a layer of oxide in the surface of the piece to enhance the behavior against corrosion.

2.2 Extrusion die

Material

The material chosen to make the extrusion die must meet the requirements of a steel for hot work tools [7], designated as F.5318 in the UNE-EN norm, equivalent to the SAE/AISI H13 steel. H13 steel, whose chemical composition is depicted in Table 3, is widely used in the production of forming tools: extrusion dices for light alloys, blanking dies, etc. The use of H13 steel gives a good balance in terms of toughness, resistance against fissure forming due to thermal shocks, quenching resistance and wear.

Table 3. Chemical composition of SAE/AISI H13 steel (%wt)

C	Si	Cr	Mo	V	Fe
0.40	1.00	5.20	1.30	0.95	rest

After tempering with non-forced air, hardness in between 44 and 52 HRC are obtained. High temperature quenching (below 540°C) allow the material to keep the hardness obtained by tempering and its resistance to be used at high temperatures: tools made with H13 steel can be used with temperatures up to 540°C, with short exposures up to 595°C. It is a first choice for making hot extrusion dices for light alloys such as the aluminum alloy of the rigid overhead catenary. Besides, it accepts nitriding to enhance surface wear resistance.

Manufacturing process

The forming of the extrusion die is made following these steps: Forging, annealing, initial machining, stress relaxing procedures, tempering, quenching, wire electrical discharge machining and nitriding.

1. Forging: The process is made at 1000°C and after that, slow cooling is performed in a furnace. It is recommended to heat the press up to 720°C to avoid high thermal contrast and consequently the wear of the press.
2. Annealing: After forging, an annealing process is performed. It consists in heating maintaining for two hours 870°C, then six hours at 760°C and, finally, non-forced air cooling. The annealing must provide a material whose hardness is in between 192 and 235 HBN that could be easily machined.
3. First machining: By turning and milling the general shape of the dies is obtained. The thickness of the die at the output must be taken into account to reduce torsions and other problems. The output profile is not obtained in this step. If wire electrical discharge machining, as is the case, is considered to provide the final profile, the hole must be done in order to introduce the wire. If other procedure is considered (for instance, laser or abrasive water jet machining) the hole is not necessary.
4. Stress relaxing procedures: After the intense machining process, it is mandatory to anneal the material in order to get rid of inner stresses above all, as in this case, when the specimen is going to be tempered and quenched. Such stresses can be the origin of defects when different local contractions and expansions are added in the tempering process. The procedure consists in heating and maintaining for two hours the temperature at 520°C. Then, a long cooling in a furnace is made.
5. Tempering: Tempering is made by heating the piece in between 995 and 1025°C. Such a temperature is maintained for 30–45min and later oil cooling. Cooling is interrupted at 650°C and cooling speed must be around 25°C/min until 650°C is reached. Thus, impact and quenching resistance is improved but strength is lightly worse.
6. Quenching: It is mandatory to quench the specimen after tempering. This procedure consists in heating at 540°C, maintaining this temperature one hour per 25mm thickness and, finally, air cooling. The hardness obtained is 52 HRC and the estimated resilience with a Charpy impact test

is 14J. This procedure can introduce a very small size increment of about 0.06%. Variations in the quenching procedure also give rise to different results. To compensate for the dimensional variations of the die, polishing and grinding should be considered.

7. Wire Electrical Discharge Machining (WEDM): An electrode of electrolytic copper wire is used to obtain the final extrusion profile. Note that at this point, traditional machining processes are not recommended due to the lack of machinability of the material after tempering and quenching. This procedure allows it to obtain complex profiles and sharp edges, and it is widely used in the manufacturing of dies. It can be used in tempered materials because material hardness does not have any influence (there is not physical contact between the wire and the piece) and the heat-affected zone can be neglected. High accuracy machining can be obtained but some manual trimming could be used [8].
8. Nitriding: The procedure is performed by heating the die at about 500°C in a furnace with a controlled atmosphere of ammonia (NH_3); then air cooling. If the process is well-done, dimensional changes are not expected because structural transformation of the steel does not take place at those temperatures [9].

4. Conclusions

The work between different areas of expertise on the same problem to be treated in different subjects can improve the communication of transversal knowledge in engineering problems, especially in manufacturing technologies.

This experience has allowed the authors to consolidate a workgroup and to start the creations of what we call "learning objects" as an instrument for teachers in their respective subjects. The interrelations of solutions are enhanced even with other areas of expertise different from the workgroup [10]. The material is mainly aimed to seminars and practice where the students can promote the discussion of different solutions.

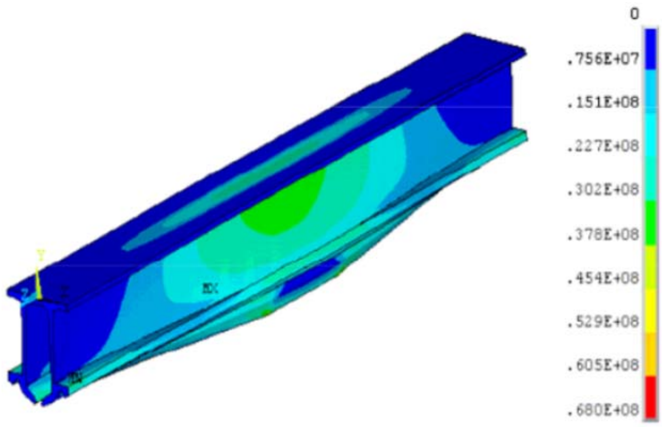

Figure32. *Integration of the project with other disciplines. Finite elements analysis of the static problem [10]*

Even though the experience and teacher viewpoint is quite positive, these kinds of innovation projects have troubles when trying to know what students exactly learn about transversal knowledge. Students are receptive to this kind of method but we have not been able to account for the improvements in their skills regarding interdisciplinarity.

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6. References

[1] H.L. Yustos *et al.* Enseñanza Integrada de "Diseño y fabricación con materiales plásticos". Primeras Jornadas de Innovación Educativa de la Escuela Politécnica Superior de Zamora. 2006.

[2] C.O. Cañizares Luna, C. Sarasa Muñoz, C. Labrada Salvat. Enseñanza integrada de las Ciencias Básicas Biomédicas en Medicina Integral Comunitaria. Educación Médica Superior, vol. 20, no. 1, 2006.

[3]G. Bengu, W. Swart. A computer–aided, total quality approach to manufacturing education in engineering. IEEE Transactions on Education vol. 39, no. 3, p. 415–422, 1996.

[4] J.D. Orjuela–Méndez, J.M. Arroyo–Osorio, R. Rodríguez–Barakaldo. Actualidad y Perspectivas En La Enseñanza Del Área De Manufactura a Estudiantes De Ingeniería. Ingeniería Mecánica, vol. 16, no. 1. pp. 59–71, 2013.

[5] S. Aguirre, C. Fuqueme, G. Zambrano. Desarrollo De un sistema de manufactura virtual y su Integración con un sistema ERP para la educación. Tecnología Informática , 2009.

[6] R.R. López–López, A. Pecharromán, A. Fernández–Cardador, P. Cucala. Transportation Research Part C vol. 38 p. 85, 2014.

[7] S.D. Henry, S.E. Frueh, R. Boring, D. Levicki, L. Harrision. ASM Specialty Handbook. Aluminium and Aluminium Alloys, ASM International, Materials Park, OH, 1993.

[8] K.H. Ho, *et al*. State of the Art in Wire Electrical Discharge Machining (WEDM). International Journal of Machine Tools and Manufacture, 10, vol. 44, no. 12–13. pp. 1247-1259, 2004.

[9] D. Bombač, *et al*. The Progress of Degradation on the Bearing Surfaces of Nitrided Dies for Aluminium Hot Extrusion with Two Different Relative Lengths of Bearing Surface. Wear, 9/30, vol. 307, no. 1–2. pp. 10-21, 2013.

[10] SEAP "Proyecto de instalación de catenaria rígida y actuaciones complementarias en los túneles urbanos de cercanías de Barcelona". Secretaría de Estado de Administraciones Públicas. Ministerio de Hacienda y Administraciones Públicas. (2008) http://www.seap.minhap.gob.es/dmsweb/es/ministerio/delegaciones_gobierno/delegaciones/catalunya/actualidad/notas_de_prensa/notas/2008/12/2008_12_15a/parrafo/00/PRESENTACI-NCATENARIAR-GIDA-definitiva-.pdf [last visited 23/02/15]