

DEVELOPMENT OF AN EXPERT SYSTEM FOR MATERIAL SELECTION OF MACHINE PARTS

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Abstract: *Engineering Material selection is a very difficult task because of unlimited available materials. This research was carried out to develop a user friendly interface that would allow an individual to filter through the large number of materials in order to find the most suitable material options for the production of some selected machine parts. Material selection mathematical models, for twenty five common machine parts, was developed using Ashby model format. The software tool used in the development of the expert system is PHPMyAdmin. This was written in Hypertext pre-processor (PHP) language designed to handle the administration of MY Structure Query Language (MySQL) server over the World Wide Web. The system was implemented using the Expert system to predict the material for machine parts of previously fabricated project. The result of these tests show that for a developed soya beans milk extraction machine, the software suggested low carbon steel for the shaft in place of mild steel used for the fabrication. Comparing the software predictions for shaft materials with standard materials (in textbooks) used for manufacturing these parts shows a greater conformity. The software is highly recommended for manufacturing industries to improve their material choice for mass production.*

Keywords: *Engineering, Material, Selection, Application, Software*

1. INTRODUCTION

Material Selection is a major aspect of engineering design. Selecting materials for different machine parts is relatively common to machine development but it is been faced with a lot of interrelated problems out of which is making adequate choice from numerous available material data base. Hence there is a need to develop a system that will make material selection easier. Several material selection systems have been developed by various authors so this work is not new but an improvement on the previous work

The development of material database has been reported by Harmer (1997), Breuer et al. (1994), Baur (1995), Michaeli (1995), Ashby(1993) and Cebon and Ashby(1992). Harmer(1997) reported that various database systems have been developed for plastics, elastomers and rubbers such as the Cambridge Materials Selector (CMS), Selector II, Plaspec, CenBASE/Materials, Mat.DB, Plastics Design Library, Engineered Materials Abstracts, FUNDUS, Prospector Plus, Polymat, SPAO, Pro-Concept, Explorer, Platt's Polymerscan, Standards Infodisk, Pira Abstracts, Packaging Science and Technology Abstracts, Chem-Intelland Weldasearch. Some of these material databases could also be used as material selection systems, but as they are mainly developed for data storage, the material selection process using a material database is not very reliable.

Computer-aided material pre-selection by uniform standards (CAMPUS) is a widely used materials database for plastics, a product similar to that of CAMPUS is a database concerned with the selection of long fiber reinforced plastics(E. Baur 1995). This system is called FUNDUS and it allows the distribution of material information from the producer to the designer (end-user). As such, it is of interest to all who work with sheet molding compound (SMC), bulk molding co features, which allow the user to view all properties for any listed product, print the data for any product or glass-mat thermoplastic materials as reported by Baur (1995) and Michaeli et al.(1995). CAMPUS and FUNDUS have search the database for products satisfying specific property requirements, select and view properties for comparison, and sort according to specific requirement in ascending or descending order.

Ashby and Cebon (1992) developed a computerized materials selection system called Cambridge Materials Selector (CMS). The system uses materials selection charts, which are a way of displaying material property data through the use of optimization procedures. The selection process depends on implementing performance indices, a combination of material properties, which if maximized, optimizes performance. The charts are developed to present the materials, and the performance indices, so that the most suitable selection of materials and shape can be carried out.

Reynard (1989) emphasized the importance of the material database and has criticized the attitude of some people who said that materials selection is not required by engineers or as a service from a computerized database. He suggested that the materials database should be presented 'in the best form suited to the needs of the users' such as by on line systems, mainframe systems, floppy disc for desktop use, and WORMS and CD-ROMS.

Waterman (1992) studied the computerized materials property data systems for meeting the requirements of design, production and materials engineers. Computerized data and information on material are available in two forms. Firstly, there are on-line systems where the subscriber to the system could contact a central computer through a local terminal-modem telephone link and secondly, personal computer-based systems where the subscriber receives data on floppy discs and accesses these through a compatible personal computer (Savoy, 2004)

According to Sharon (1992), some bottlenecks are identified as being important in concurrent engineering. These are people, early decision making capability and feedback-facilitating technologies. Early decision making is seen as important because normally, engineering work begins without sufficient information. Current decisions have to be made in the early design stages. Therefore, computer systems play an important role in providing information to design engineers.

However, none of this aforementioned researchers have been able to critically induce most of the material properties which is included in this current work into theirs, thereby still given little chance for inadequate prediction of material to be used for a particular design. Thus, this work takes into consideration a lot of properties ranging from the thermal properties, electrical properties, mechanical properties .etc. and also a mathematical model is also imbedded which enable users to calculate each material property which are not given directly and these will in turn give space for proper prediction of the material. Machine parts or products generally can be predicted after filling in the properties of the expected material or after using this same expert system to calculate the properties expected.

2. MODEL DEVELOPMENT

The steps used for the development of the material selection models are;

- i. identification of material selection requirements
- ii. identification of material property equations needed for the model development
- iii. model equation development

2.1 Development of Material Selection Model for Shaft Subjected to Twisting Moment Only

From Twisting Moment and Torsional Shear Stress equation

$$\frac{T}{J} = \frac{\tau}{r} \quad (1)$$

Where,

T= the twisting moment (torque) acting on the shaft

J=polar moment of inertia acting on the shaft about the axis of rotation

τ = torsional shear stress

r =radius distance from neutral axis to outer fibre

For solid shaft , $J = \frac{\pi}{32} \times d^4$;

$$r = \frac{d}{2}$$

$$\text{Therefore, } T = \frac{\pi}{16} \times \tau \times d^3 \quad (2)$$

$$\text{For hollow shaft : } J = \frac{\pi}{32} \times (d_o^4 - d_i^4),$$

$$r = d_o/2,$$

Where,

d_o and d_i are the outer and inner diameters of the hollow shaft

Therefore,

$$T = \frac{\pi}{16} \times \tau [(d_o^4 - d_i^4)/d_o] \quad (3)$$

The Shaft must carry moment, M_t , with length L . therefore the relationship between Mass and torsional shear stress is given as

$$\tau = 2M/\pi R^3 \quad (4)$$

In order to derive the Performance Equation for this shaft, the Strength relation is given as:

$$\frac{\tau}{s} = 2M/\pi R^3 \quad (5)$$

and Mass of the shaft is ,

$$m = \rho \pi R^2 L \quad (6)$$

Substituting the strength equation in to the mass formula;

$$m = (2\sqrt{\pi} \times s \times M)^{2/3} L (\rho/\tau^{2/3})$$

Therefore the performance index is to maximize

$$M = \tau^{2/3} / \rho \quad (7)$$

2.2. Development of Material Selection Model for Shaft Subjected to Bending Moment Only

Bending moment equation

$$\frac{M}{I} = \frac{\sigma b}{y} \quad (8)$$

Where,

M = bending moment

I =moment of inertia of cross-sectional area of the shaft about the axis of rotation

σ_b =bending stress

y =distance from neutral axis to the outer-most fibre.

$$\text{For solid shaft: } I = \frac{\pi}{64} \times d^4 ; y = \frac{d}{2}$$

$$\text{Therefore, } M = \frac{\pi}{32} \times \sigma b \times d^3 \quad (9)$$

$$\text{For hollow shaft : } I = \frac{\pi}{64} \times (d_o^4 - d_i^4) \text{ and } r = d_o/2,$$

Where,

d_o and d_i are the outer and inner diameters of the hollow shaft

Therefore,

$$M = \frac{\pi}{32} \times \sigma b [(d_o^4 - d_i^4)/d_o] \quad (10)$$

The shaft must be able to withstand a bending load, F and must have minimize mass,

$$m = b^2 L \rho,$$

Where,

ρ is the material density.

The Performance Equation can be developed considering the fact that the beam must be strong enough so that it does not fail due to an applied bending moment, M , due to the load, F . Thus, the

Performance Equation can be given as:

$$\frac{M}{L} \leq (C) \left[\frac{I}{b/2} \right] \left[\frac{\sigma_Y}{L} \right] \quad (11)$$

Where,

σ_Y is the yield strength of the material and

I is the second moment of area, $I = b^4/12$

The Performance Equation can now be rewritten by substituting one of the free Variables (edge length, b) as;

$$m \geq \left[\frac{6M}{CL} \right]^{2/3} (L)^3 (\rho / \sigma_Y^{2/3}), \quad (12)$$

Where $M=F/L$

Therefore the material index is,

$$M_3 = \sigma_Y^{2/3} / \rho$$

That is the material with higher value of M_3 is expected to perform better in comparison to a material with lower value of M_3 . In other words, the Material Index (M_3) allows the examination if a material with higher weight (density) has to be selected to ensure that the same has sufficient strength (i.e. σ_f) to avoid failure during service.

2.3 Development of Material Selection Model for Design of Shaft Based on Rigidity (i.e. Torsional Rigidity)

$$\frac{T}{J} = \frac{\tau}{R} = \frac{G\theta}{L}$$

$$\theta = \frac{T.L}{J.G}, \quad (13)$$

Where,

θ = Torsional Deflection or Angle of Twist in Radians

T = Twisting Moment or Torque on the Shaft

J = Polar Moment Of Inertia of the Cross-Sectional Area about the Axis of Rotation

For Solid Shaft, $J = \frac{\pi}{64} \times d^4$ (14)

and $J = \frac{\pi}{64} \times (d_o^4 - d_i^4)$, For Hollow Shaft (15)

The constraint here is that Bar must not lengthen by more than δ under force F ; for initial length L .

Stiffness relation is given as:

$$F/c^2 = \frac{E\delta}{L} \quad (16)$$

Where $\sigma = E\epsilon$

Therefore from Mass of bar, $m = \rho Lc^2$

Substitute;

$$m = (FL^2 / \delta) (\rho/E) \quad (17)$$

The performance index is given as;

$$M = E/\rho \quad (18)$$

3. SOFTWARE DEVELOPMENT

3.1. Material Data collection and database design

Material properties such as young modulus, shear stress, density etc were gathered from reliable sources such as books journals, articles research institutes and online. Database management system (DBMS), will used to set up, or structure a database. It can also be used to retrieve information from a database. My SQL database which is a branch of the Windows Apache MySQL php My Admin server (WAMP server) will used in creating the database and this designed database will communicate with the software with the aid of a language called Structured Query language (SQL). The reason for selecting the My SQL database is its good compatibility with Microsoft Visual Studio 2010

3.2. Development of the expert system

The software tool used in the development of the expert system is PHPMyAdmin. This was written in Hypertext pre-processor (PHP) language designed to handle the administration of MY Structure Query Language (MySQL) server over the World Wide Web. The flow of the material selection process shown is shown in Figure-1 given below.

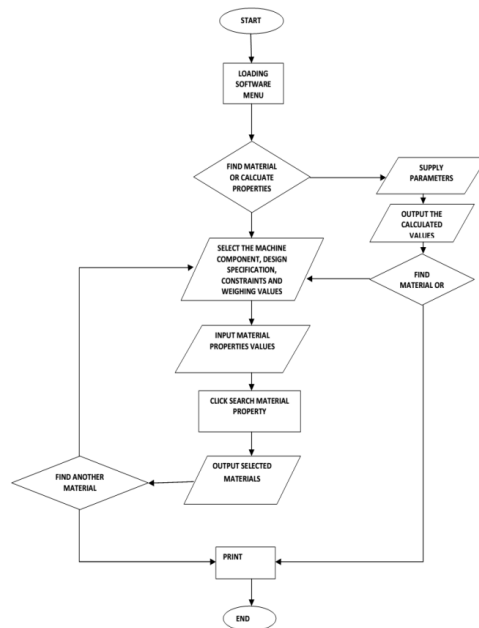


Figure 1: Software flow chart

a. Methodology (System usage)

The main menu interface (Figure.2) begins the client/ user side of the package. On this interface, we have the scroll of machine components, design specifications, constraints and the weighing values. The design specification has three options which are stiffness limited designs; strength limited designs and damage tolerance design (Figure.3). The constraints in this case means if the machine part have some specified shape, dimensions such as specific radius.

The weighing values takes into consideration the goal of the selector i.e. design with minimum mass, minimum cost or minimum energy.

The result interface (Figure. 4) displays the suggested material by the software. The interface is designed to display five optional materials with their respective material index value. Also this interface can be printed. Also the expert system has a material property calculator (Figure.5)

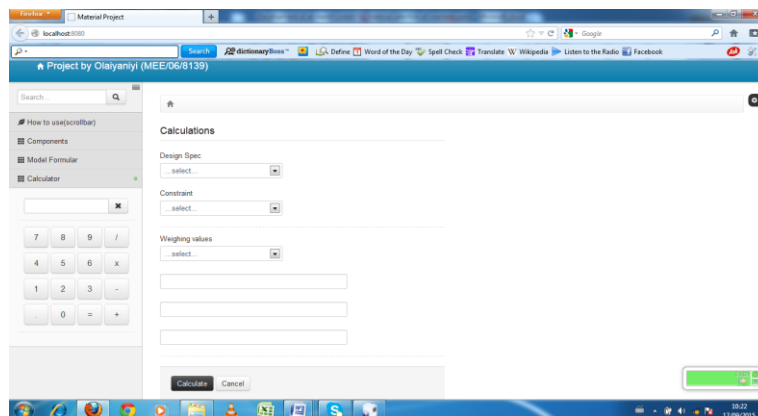


Figure 2: Main menu

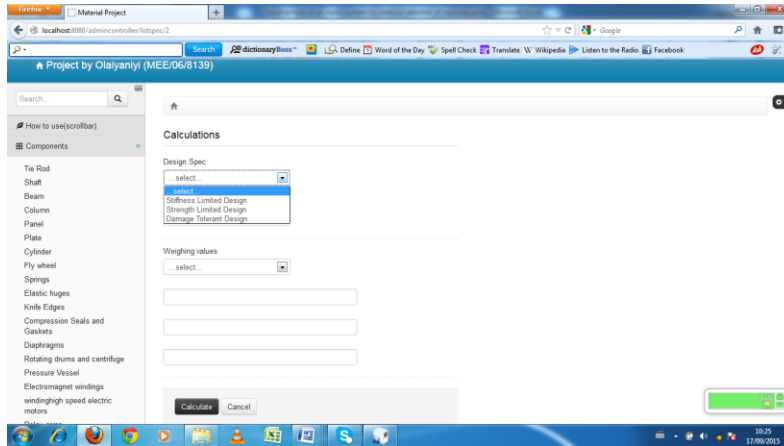


Figure 3: Design Specifications

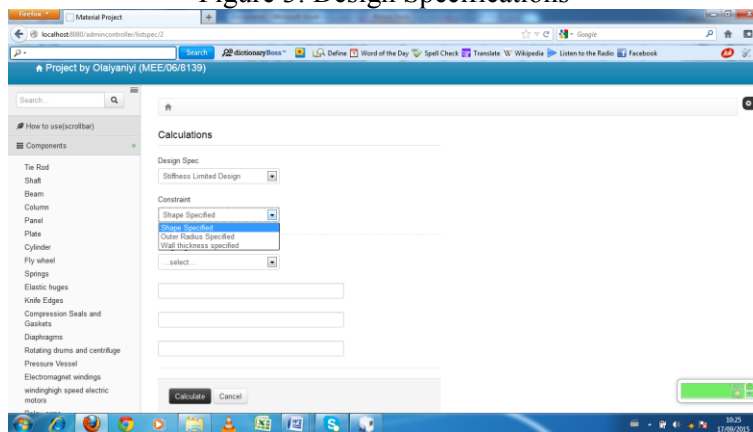


Figure 4: Design Constraints

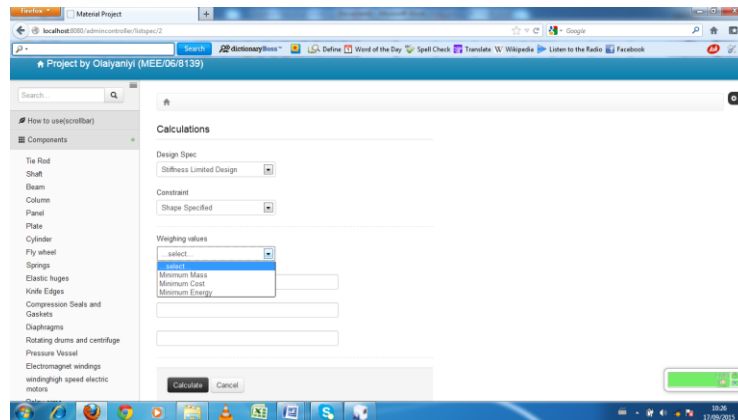


Figure 5: Weighing values

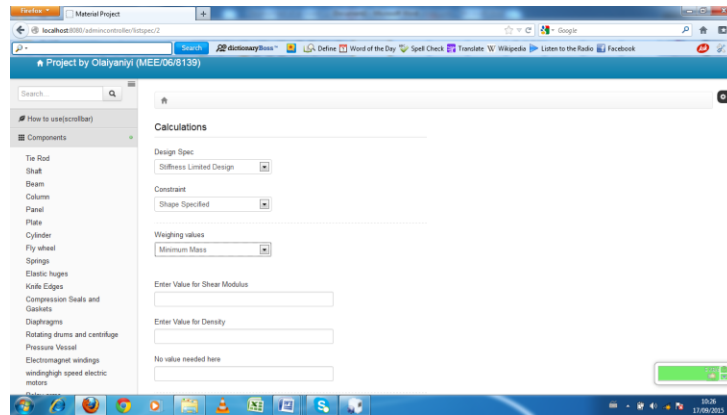


Figure 6: Input Values

4. RESULT AND DISCUSSION

Table 1 given below shows the results of the software prediction compared with the standard material for some machine parts. Generally for shaft manufacturing stainless steel or alloy steel grades with nickel-chromium additives are use which conforms to the system prediction (Figure 6 and 7).

Also for machine plate, stainless steel is used because it is not poisonous but the software suggested SiC/SiC Fibre, 35-45Vf – Woven Laminate (Figure 8), which is also not poisonous and non corrosive. This discovery can be further verified by manufacturers. In the case of machine pulley, high speed tool steel is predicted (Figure 9) by the system but in other to reduce the cost most fabricators use low carbon steel or grey cast iron.



Figure 6: Software prediction for shaft (rigidity)

Table 1. Software Predictions

RESULTS					
Machine part	Material properties		Model	Prediction	Standard material
Solid shaft(rigidity)	Modulus of elasticity(E) (210KN/mm ²)	Density(ρ) (2845 Kg/m ³)	M=E/ρ	low alloy steel (annealed)	Stainless steel
Plate	Modulus of elasticity(E) (210KN/mm ²)	Density(ρ) (2845 Kg/m ³)	M= E ^{1/2} /ρ	SiC/SiC , 35-45Vf	Stainless steel
Solid shaft(bending moment)	Yield stress (σ _Y) (245-275)N/mm ²	Density(ρ) (7207 – 7750.4 Kg/m ³)	M= σ _Y ^{2/3} /ρ	Low alloy steel AISI 8740 (quenched &	Stainless steel

				tempered)	
Pulley	Tensile strength (448.159 MN/m ²)	Density(ρ) (7207 -7750.4 Kg/m ³)	$M = \sigma_f \rho$	Molybdenon high speed toolsteel (AISI M10)	Grey cast iron

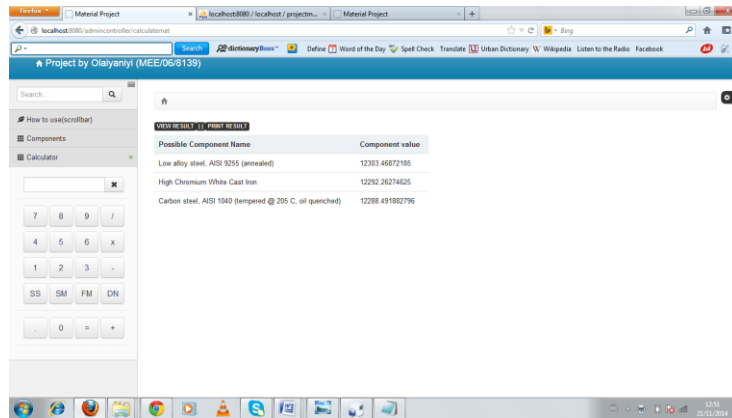


Figure 7: Software prediction for shaft (bending moment)

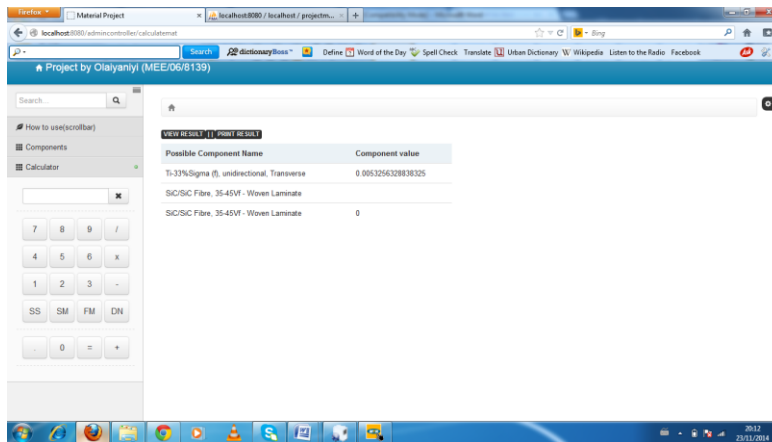


Figure 8: Software prediction for plate

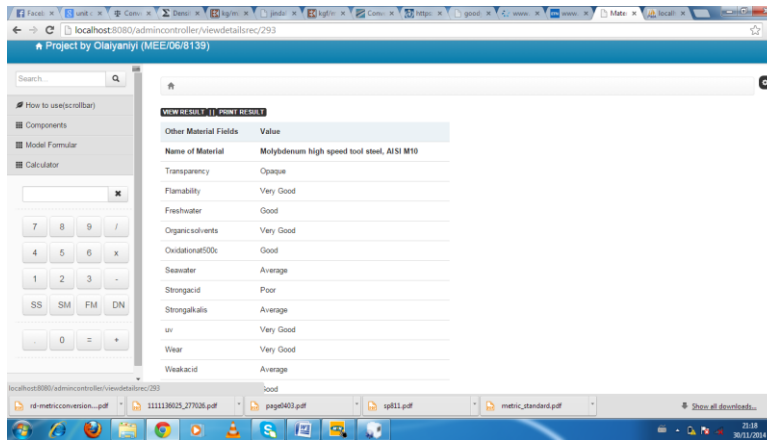


Figure 9: Software prediction for pulley

5. CONCLUSION

The above analysis and tests shows that this system software satisfies its intended reason for development which are, its ability to calculate material properties and also to be able to predict near accurately if not accurately the material to be used for machine or machine parts development.

REFERENCES

1. Ashby, M.F 2000. Materials selection in mechanical design. Oxford: Pergamon Press.
2. Borak, D. 2008. Material selection in gear design, Faculty of technical science, Novi Sad
3. Callister, W.D 2000. Materials Science and Engineering Materials: An Introduction, Fifth Edition. John Wiley & Sons, New York.
4. Cebon, D.; and Ashby, M.F 2003. Data system for optimal material selection, advanced materials and processes, vol. 161, No.6, pp 51 – 54
5. Machinck, H; and Thompson, S. 2005 Project report; Application of material design methods.
6. Savoy, J. 2004. Bibliographic Database Access Using Free-Text and Vocabulary; An Evaluation, Information Processing and Management.
7. Shackelford, J.F. 2000. Introduction to Materials Science for Engineers, 5th Ed., Prentice Hall
8. Barrett, C.S. 1985. Crystal Structure of Metals, Metallography and Microstructures, Vol. 9, Metals Handbook, 9th ed., American Society for Metals, P 706-719
9. Baur, E. 1995. English version of FUNDUS material database. ReinfPlast; 39(4):21.
10. Bittence, J.C. 1983. When computers select materials. Mater Eng; 93(1):38-42.
11. Bray, J.W. 1997. Aluminum Mill and Engineered Wrought Products ASM Handbook, ASM International USA, P 29-60.
12. Breuer, H.; Tiba, M.H.; Shastri R *et al.* 1994. Global standardization of plastics data. Automot Eng.; 102(8):13-15.
13. Dodd, G.S; and Fairfull, A.H 1989. Knowledge-based systems in materials selection. In: Dyson BF, Hayhurst DR, editors. Materials and engineering design: the next decade. London: The Institute of Metals.
14. Froth, R.; Field, F.; and Clark, T. 1994. Materials Selection and Multi-Attribute Utility Analysis, J. Computer-Aided Materials, Des. Vol.1 (No.3), ESCOM Science Publishers, Oct. 1994, ASM International P 243-254.
15. Gubiotti, R.A 1986. Future trends in numeric database and software development. Proceedings of the Thirty First International SAMPE Symposium. USA.
16. Gutteridge, P.A.; and Waterman, N.A. 1986. Computer-aided materials selection: Bever MB, editor. Encyclopedia of materials science and engineering. Oxford: Pergaman Press.

17. Harmer, S. 1997. Materials databases I. London: Materials Information Service, The Institute of Materials.
18. Jack, W.B. 1997. Aluminum Mill and Engineered Wrought Products, ASM Handbook, ASM International USA, P 29-60.
19. Jackson, B. 1994. Computerized Materials Databases and Systems. Iron making and Steel making. Vol. 21, No. 4, pp. 262-263.
20. Michaeli, W.; Kleine, E.; Heber, M.; and Semmler, E. 1995. FUNDUS. Kunststoffe;85(1):54.