Material Selection Techniques by Using Computer

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Abstract

This research is concerned in showing the importance of material selection in production design stage, the factors that involved the material selection strategies and its criteria and the modern approach of materials selection since there are many techniques of material selection. The proposal work helps in choosing the following appropriate techniques from many quantitative ones. The following techniques (Geometrical approach, Algebraic Approach), were included in the work the developed system solves the selection techniques and introduce the best material from a database contains the steel family.

The case study was examined from the real world of manufacturing and satisfactory results were obtained. The developed algorithm is being to build Material Selection Techniques system called MASTECH which incorporates making decision on materials selection.

In the research, MASTECH system has been developed to aid both designers and manufacturing engineers in choosing the most suitable material.

Keywords: materials selection, geometrical approach, algebraic approach.

تقنيات اختيار المواد باستخدام الحاسوب

الخـــلاصـــــة

ان هذا البحث يتضمن دور واهمية اختيار المواد في عملية التصميم والعوامل و المعـــايير المؤثرة في اختيار المادة وكذلك الاسلوب الحديث لهذه العملية واخيرا التقنيات التي تم استخدامها في عملية الاختيار والتي تم اختيارها من عدة تقنيات وهي (التقريب الهندسي، التقريب الجبري) تـــم استخدام هذه التقنيات وذلك لانها تحقق النتائج المطلوبة والتي تظهر الخواص الميكانيكية والكيميائية والكلفة المطلوبة.

البحث المقدم يتضمن تصميم وتطوير نظام لحل مشكلة اختيار المواد لمساعدة المـــصممين في اعمالهم، لذا فان هذا البحث يعنى بايجاد حل لمشكلة اختيار المواد، حيث ان مهمة البحث تحـــدد في ايجاد حل لمشكلة اختيار المواد هي ايجاد افضل مادة تحقق المواصفات المطلوبة اســـتاداً الـــى قاعدة البيانات المتوفرة للنظام حيث ان جميع المعطيات الخاصة بالسبائك وفـــق المقـــاييس العالميـــة والتي، تم حصرها هنا بسبائك الفولاذ والهدف من هذا النظام هو ايجاد دعم وتسهيل لمهمة المـــصمم

Theoretical part

Introduction

Motivations for materials selection can be either the realization of a completely new product or, more frequently, the substitution of an existing material. In the latter case, performance's improvement and cost reduction can be the main driving forces for selection. Generally any materials selection event must consider a large number of material candidates and premature exclusions must be avoided. Also, when facing a material selection problem, engineers are normally asked

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to choose a solution which satisfies more than one objective, that is, not only lower weight, but (for instance) also low cost, good fatigue resistance, better fabricability etc [1].

The basic question is how we go about selecting a material for a given part. This may seem like a very complicated process until we realize that we are often restrained by choices we have already made [2].

In recent years, the concept of Concurrent Engineering (CE) has emerged aiming to enhance the competitiveness of product. It calls for improving quality, reducing cost, speeding up delivery of product and bringing out development by applying a management science approach in product development processes and innovating development organization and operations.

The MASTECH starts solving by using the chosen technique accompanied with a search in the developed database to suggest the most suitable material to the specified requirements. In this work the steel family is included in the developed database and can be extended in the future to include more families of different materials.

Aim of Research

1- A computerized system is being introduced to automatically select a quantitative material selection technique from many for a better performance in materials selection.

2-Using material selection techniques to get the best material that meet the design requirements by reducing time, and cost of engineering material that is being selected with high accuracy.

The Role of Selection of Material in the Design Process

Engineers always try to improve a design, but it is rare that an optimal design is achieved. Optimal designs require a creative approach to select the best material to best perform all the functions of the design while also varying the shape and the process to manufacture the product [3]. Optimal designs require the best interaction of function [F], material selection [M], shape or geometry [G] and manufacturing process [P] as shown in Fig (1)

Stages of Selection of Material in the Design Process

Degarmo, Kutz and Hyman have classified the design process into the following phases [5-7]:

(1) conceptual, (2) functional, and (3) production design. The Material selection within these phases is as follows:

1-During the conceptual design stage:

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At this stage, the only thought given to material selection is whether materials are available that will provide the properties that are required. Involves analyzing and clearly stating the problem. And the designer (team) collects and writes down all the requirements and constraints, the standards to be adhered to, statutory requirements, the projected data of completion of the design project.

2-At the functional-or engineering design stage:

A practical, workable design is developed. Usually, fairly complete drawings are made, and materials are selected and specified for the various components. Often a prototype or working model is made that can be tested to permit evaluation of the product as to function, reliability, appearance, and serviceability and so on.

3-At the production-design stage:

The primary concern relative to materials should be that they are specified fully, that they are compatible with, and can be processed economically by the existing equipment, and they are readily available in the needed quantities.

Selection of Material Criteria

The selection of the material is done with following criteria considered

concurrently with the performance and the cost of the material as paramount factors [8]:

1-Performance   Characteristic (Properties):

Selection based on property profile is the process of matching the numeric values of the properties of the material to the constraints and requirements.

2-Procssing Characteristics:

Selection based on processing is aimed at identifying the process that will form the material to the desire shape and then join and finish it at a minimum cost. It is a complex task because of the very large number of processing methods and sequence possibilities.

3-Environmental Profile:

Selection based on the environmental profile relates to the impact of the material its manufacture, its use and its disposal- on the environment.

4- Business Considerations:

The chief business consideration that affects materials selection is the cost of the part that is made from the material. This considers both the purchase cost of the material and the cost to process it into a part.

Systematic of Selection of Material

In more detail, Dieter [9], Clauser [10] and Ashby [11] describe the materials selection process as the one, which

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involves four major operations, which are: -

1-Analysis of the materials application problem: This requires a study of the performance, physical attributes, and application conditions.

2-Translation of the materials application requirements to materials property values.

3-Selection of candidate materials:

Once the require properties are clearly specified, the rest of the selection process involves the search for the material that best meets these properties. In choosing candidate materials, any one or more of a number of criteria can be used.

4-Evaluation of candidate materials:

The objective of the evaluation step is to weigh the "candidate materials "against the specified properties to find the one best suited for the application.

Selection of Material Techniques

There is no method or a small number of methods of material selection that have evolved to a position of prominence. In a general sense a variety of approaches to materials selection are followed by designers and materials engineers. Some of the more common and more analytical methods of materials selection are: [8, 9, 12, 13]

1- Cost vs. performance indices.

2- Decision Matrices:

Weighted property indices.

Digital Logic Method.

Performance Index.

Rating Chart.

Pugh Method.

3- Incremental return method.

4- Geometrical approach.

5- Algebraic approach.

6- Benefit-cost analysis.

7- Limits on properties method.

8- Value analysis.

9-Other

Digital Logic Method

In the cases where numerous material properties are specified and the relative importance of each property is not clear, determinations of the weighting factors (w) can be largely intuitive, which reduces the reliability of selection. The digital logic approach can be used as a systematic tool to determine (w). In this procedure evaluations are arranged such that only two properties are considered at a time. Every possible combination of properties or goals is compared and no shades of choice are required, only a yes or no decision for each evaluation. To determine the relative importance of each property or goal a table is constructed, the properties or goals are listed in the left-hand column, and comparisons are made in the columns to the right, as shown in Table (1). In comparing two properties or goals, the

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more important goal is given numerical one (1) and the less important is given zero (0). The total number of possible decisions[9]

$$N = n (n - 1)/2 \qquad \ldots\ldots\ldots(1)$$

where *n* is the number of properties or goals under consideration.

A relative emphasis coefficient or weighting factor (w_i) for each goal is obtained by dividing the number of positive decisions for each goal (*m*) into the total number of possible decisions (*N*). In this case $\sum w_i = 1$ [8, 9].

Geometrical Approach

An ideal material for a specific application may be geometrically represented in the form of a regular polygon with various properties plotted along radials from the polygon center to each vertex. Five properties forming a pentagon might be strength, electrical conductivity, corrosion resistance, density, and cost. Values for each property are thus defined as Y_1, Y_2 ...and Y_n. These may be represented as equal distance radials.

A candidate material for the application may then be considered with its respective properties –designated X_1, X_2 ,……,X_n plotted along each radial, clearly the suitability of a candidate material can be rated according to three factors [12]:-

The size of the polygon and its closeness to the ideal.

The shape of the polygon and its closeness to the ideal.

The subjective assessment of the importance of deviations from the ideal.

Any number of properties might be represented on such polygon, including say, module of elasticity, hard nesses, thermal conductivities, expansion coefficients, magnetic properties, corrosion rates for various environments, etc. Generally these are all positive quantities. The multidimensional problem may be reduced to only two dimensions as follows. A ”Mean Weighted Characteristic” (MWC) may be defined by[12]:

$$MWC = \frac{\sum\limits_{i=1}^{n} \dfrac{w_i X_i}{Y_i}}{\sum\limits_{i=1}^{n} w_i} \qquad \ldots\ldots (2)$$

where n is the number of properties and (w_i) is a weighting coefficient arbitrarily chosen from 0 to 1 according to the relative importance of a particular property, zero being unimportant and unity being a critical property. However, in limiting cases, when many (w) values are set equal to zero, the

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concept is not strictly true. Likewise, a "balance factor" (BF) may be defined as a root mean square deviation given by[12]:

$$BF = \sum_{i=1}^{n} \sqrt{\left(\frac{X_i}{Y_i} - MWC \right)^2} \qquad \ldots\ldots (3)$$

The closer the Bf is to zero, the nearer the shape of the candidate material polygon to that desired. The rating procedure or criterion for a materials selection is choosing those having minimum values of [12]:

$$\sqrt{(1-MWC)^2 + (BF)^2} = d \qquad \ldots.(4)$$

Algebraic Approach

A very direct approach to choosing materials from a data bank is to base the selection process on minimizing the sum of the per unit deviations of the properties of candidate materials from the specified properties are designated Y_i, the properties of candidate materials are X_i, and the weighted coefficients are w_i as before, than the criterion is expressed algebraically as follows [12]:

$$\text{Min } Z = \sum_{i=1}^{n} \left| w_I \frac{X_i}{Y_i} - 1 \right| \qquad \ldots.. (5)$$

The algebraic approach to the materials selection problem is based on the above simple algorithm. However, the use of interactive computer terminal permits significant improvements without adding greatly to the demands on the program user. The algebraic approach recognizes this range of possibilities and thought the computer terminal asks the user for each specified property whether the limit is upper, lower, or target. The algorithm above incorporates these directional limits by introducing the following constraints:

$X_i / Y_i > 1$ for upper limit on property i

$X_i / Y_i < 1$ for lower limit on property i

$X_i / Y_i = 1$ for target property i

When a limit is not violated there is no contribution to Z.

In the algebraic approach, using a data bank of materials, the selection process ignores materials if any property goes outside limits by a weighted value of (0.4). In symbolic form, materials are listed if and only if [12]:

$$w_i \frac{X_i}{Y_i} - 1 < 0.4 \qquad \ldots.(6)$$

Experimental parts
Intoduction

An automated advisory system for material selection techniques (MASTECH) is being designed nd developed as a tool for industrial engineers, in the production design stage to select the best material.

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Developing such a system aims to help to improve quality of products, reduce the required period time of production and cost, and increases the efficiency of the production and to provide a great performance at lower cost.

The MASTECH-system is built using Visual Basic language (version 6) while integrated with Microsoft Excess database environment, and developed on a Pentium (III) PC.

MASTECH-System Characteristic

The main target of this system is:

1- The system helps in finding the suitable material selection technique according to the inputs required by the user.

2- It solves the problem and provides the best choice of material for an application.

3-For an experienced designer, he/she can choose directly the specific technique and proceed in solving the problem automatically by the system after providing the adequate input.

MASTECH-System Architecture

The architecture of the developed system consists of the two following phases:

Phase1:- Selection of Material Techniques Module.

Through this module, the system will help the user in selecting the material selection technique(s) according to the

provided input. The techniques included are quantitative techniques geometrical approach, algebraic approach. The output of the results is viewing the technique that is selected to be used in phase2.

Phase2: Selection of Material Problem Solving Module.

This module is activated after going through the first modules where the system starts to solve the problem of materials selection according to the technique chosen from the previous step. The result will be suitable materials that meet the design requirements.

MASTECH-System Databases

Database system is provided with a big number of data and information because the modern techniques of database have more importance in selection approves and also for selects the best material.

The developed system includes two databases:

1-Selection of Materials Techniques Database:

This database can be classified into two gropes:

Product Input Data.

Selection of Material Techniques Databases.

This database contains a number of methods of engineering selection materials, which are listed so as to

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enable the searcher to use them in this program either manually or automatically.

2- Selection of Material Problem Solving Databases:

This database includes two groups:

Selection of Material Problem Solving Databases.

Materials Databases.

This database includes mechanical properties and chemical composition of many steel alloys arranged in style to make a comparison between the alloys according to optimal properties of adequate alloy for our product that is chosen by the searcher.

The MASTECH–System Application

The researcher has developed an automated system to select first appropriate material selection technique and second solve the problem by selecting the suitable material. Automating the quantitative material selection technique helps in resolving many problems dealing with material type through primary design stage. The system is especially useful in manufacturing environments that demands short lead times.

1- Description of the product:

The product properties can be described through studying the design of the product provided from the Engineering Department in the State Company for Construction Industries .

2- The Properties of the Products:

The Pinion Properties: fig(2, 2a,2b)

Product Name or

Classification: (X)

Ultimate tensile strength: 430MPa

Yield strength: 279 MPa

Reduction in area %: 50

Hardness HB: 120

Shear Modulus: 80 GPa

Density: 7.8 g/cc

Cost: 380 $/tone

MASTECH- System Operation

1-The Main Window of MASTECH System:

The first stage of the system is the main window. The system contains a group of primary and secondary windows that represent the execution of the system used to select the best material.

The MASTECH system implementation requires interaction between the designer and the functional modules. The arrangement of functional modules allows the designer to implement the functional modules respectively without having any effects on the overall system structure

The system was implemented on Pentium-III and developed using Visual Basic language. To explain the execution of the system, the major

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functional modules are discussed in detail as follows. After that the product properties is identified by the user, as shown in Figure (3), the product properties are the main important input that needs to be defined by the user to be used in other operations. This window represents the main interface of the system because of the icons, which represent the basic functions to execute the system, and these icons are (*New Search, Weighting Factor, Material Selection Automatically, Material selection Manually*). The system provides the capability to update the value of each property by the user. Figure (3) Material selection techniques used in the system are geometric approach and algebraic approach. Every technique starts when the user clicks on the icon of this method then the system starts directly the comparison and processing to the value and properties of many alloys through the certain approach which is considered solving the material selection problem.

Before the designer chooses the method he should start with the (*Weighting Factor*), so, the system directly goes to another interface which can calculate the weighting factor by Digital Logic Method to make a comparison between the properties. As a result the user will have weighting factors that will be used

later in the MASTECH system. Figure (4) depicts the weighting factor window.

MASTECH- System Testing

To examine and test the capabilities of the developed methodology are carried out mechanical parts are selected as an example for testing the system. The part design models selected are taken from the real world chosen from the manufacturing environments of the State Company for Construction Industries, Examining and testing the capabilities of the MASTECH system are carried out as follows:

1-Selecting material by using geometrical approach is through output results of geometrical approach screen. Fig (5)

2-Selecting material by using algebraic approach is through output results of algebraic approach screen. When the user clicks on the *Candidate Material(s)* a secondary window will appear that asks about the limit of the properties to select the best material. Fig (6)

3-Description of the weighting factor of the part is through output results of weighting factor screen for pinion. Fig (7)

Final Results

This function is the last stage which consists of viewing the final results for choosing alloy when the user pushes

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icon of *Find Steel Type*. By this icon system will view the data of perfect selection of material where this data consists of properties and chemical composition of material as shown in Figs (8) and (9), The output results of system is divided into eleven levels and obtained as follows:

1-Output results of geometrical approach screen for pinion. Fig (8)

2-Output results of algebraic approach screen for pinion. Fig (9)

Discussion

The basic aim of designing this system is to construct a system for material selection in the production stage of design function so as to get the best results for the alloys according to their properties. This aim can be cleared after examining the developed system (MASTECH) through the chosen case studies, which lead to find the best alloy and its alternative, so the results that appear in the (MASTECH) system are:

For the Pinion (X):

Selection of Material Techniques	1st Selection	2nd Selection
Geometrical Approach	1117	1025
Algebraic Approach	1117	1020

The best alloy and alternative alloys that are chosen from MASTECH system, meet the requirements and their properties are as shown in below:

Steel AISI 1117 is more ductile than the lower manganese grades and will stand somewhat sever cold deformations. It has better mechanical properties than Bessemer steel but is not as machinable. The steel 1020 is somewhat stronger and less easily formed cold. In the case hardened condition it has higher core strength. After we get the overall results we know that the (MASTECH) has enough ability to support designer through the very production stages of design which make them able to suggest and take good decision against the basic problem that they phased. It is connected with material selection.

Conclusions

1-In the (MASTECH) system we find that each of Geometrical Approach, Algebraic Approach, has high accuracy because the results which appear in the system refer to the alloy which meets the requirements.

2-The MASTECH system offers designers and manufactures an insight into the fast developing world of steel materials in order to meet the objective of producing lower cost, higher quality, and better performance products.

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3-The (MASTECH) system serves not only to select the steel material(s) for a product, but it also serves to evaluate the selected material(s) economically. The economic evaluation procedure will be performed by the system through using a quantitative approach, based on mathematical algorithm.

4-The necessary part of MASTECH system appears to construct an accurate database which includes many detailed information about alloy, which leads users to get a maximum useful level.

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Table (1) Determination of Relative Importance of Goals [12]

Goals	Number of Positive Decisions $N = n(n-1)/2$										Positive Decisions	Relative Emphasis Coefficient w
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
1	1	1	0	1							3	0.3
2	0				1	0	1				2	0.2
3		0			0			1	0		1	0.1
4			1			1		0		0	2	0.2
5				0			0		1	1	2	0.2
Total number of positive decisions											10	$\sum w = 1$
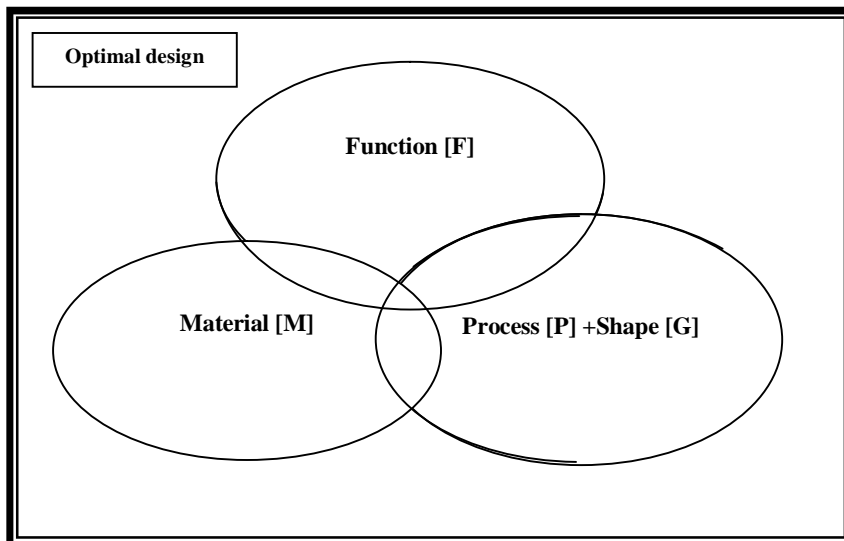
Figure(1) The best interaction of function, material selection, shape or geometry and process[4].

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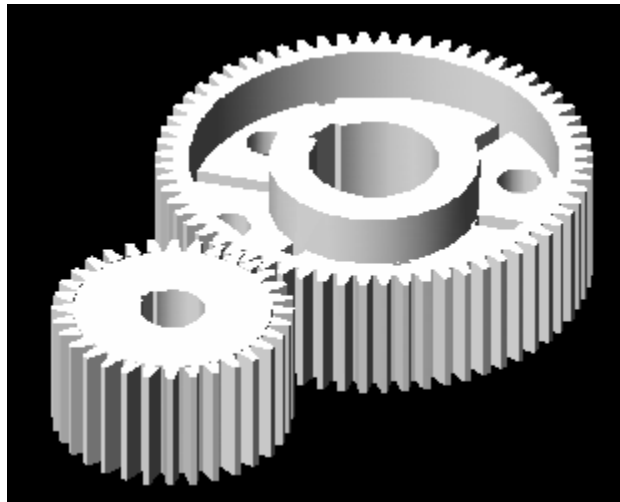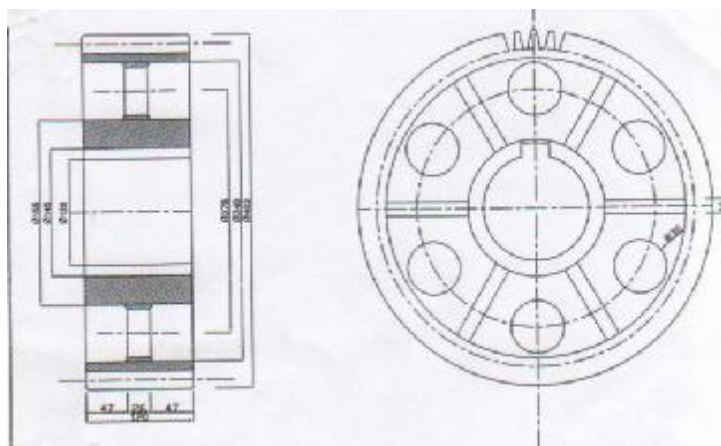
Figure (2)

Figure (2a) Engineering drawing for gear
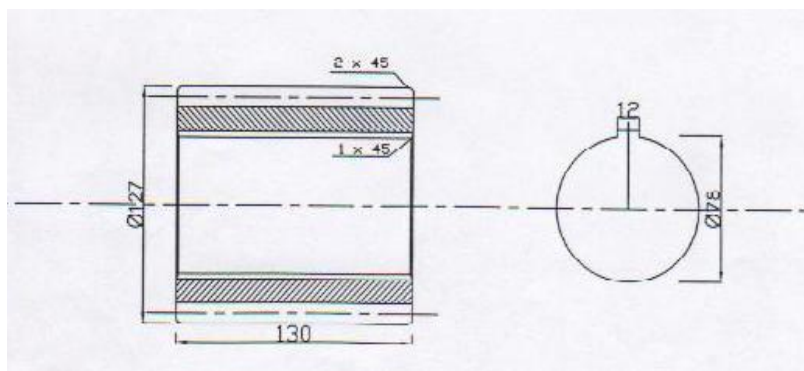
Figure (2b) Engineering drawing for pinion
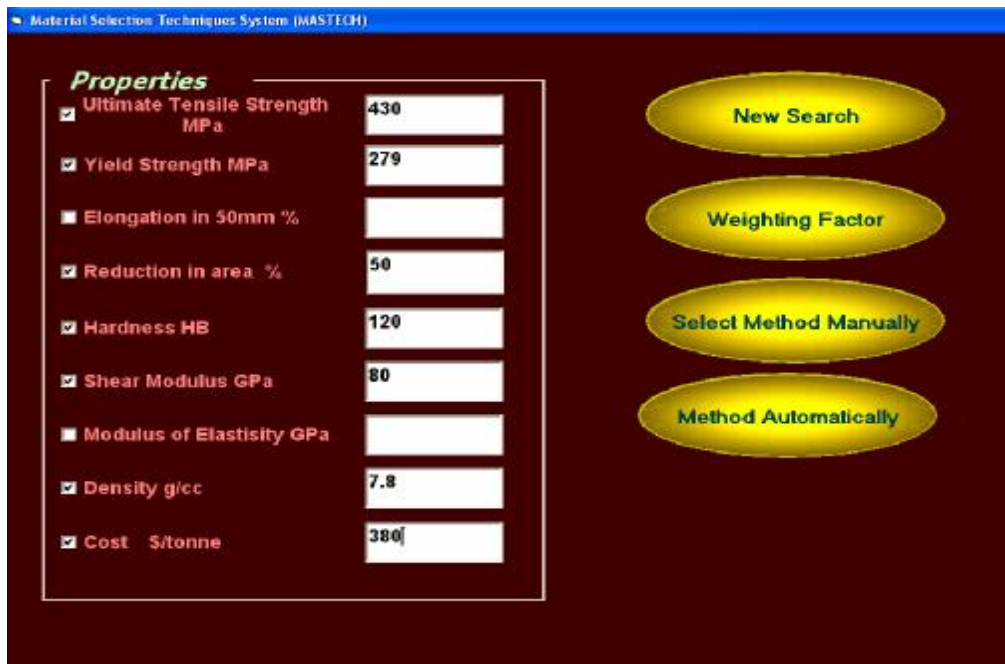
Figure (3) The Main Window of MASTECH System

Figure (4) Weighting Factor Window
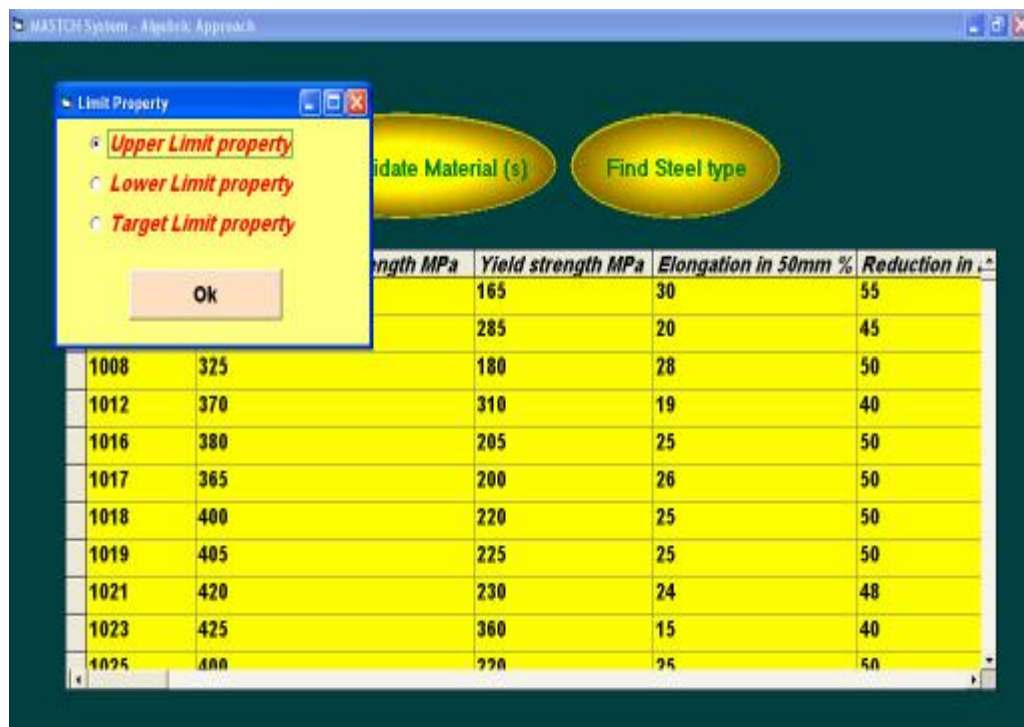
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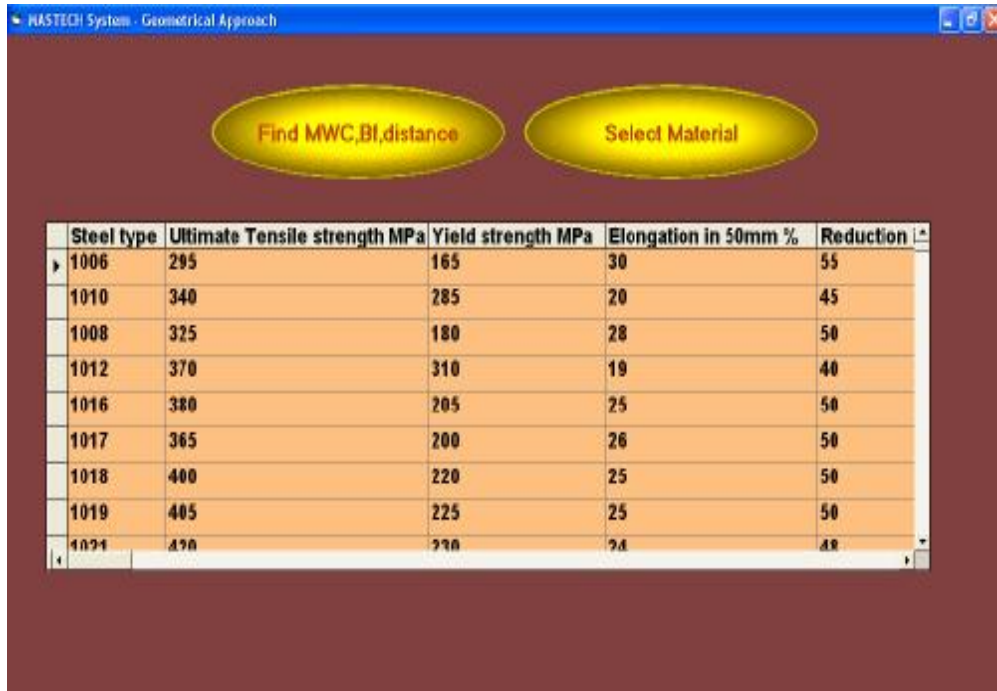
Figure (5) Geometrical Approach Window

Figure (6) Algebraic Approach Window

Figure (7) Output Results By Weighting Factor Window for pinion.

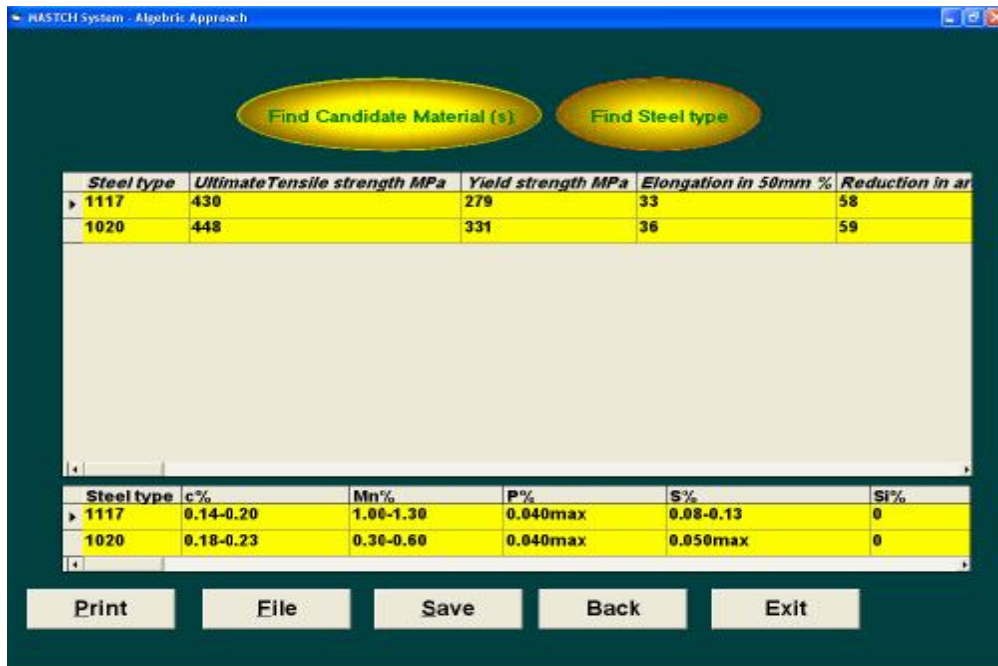**Figure (8) Output Results Of Geometrical Approach Window For Pinion**

Figure (9) Output Results Of Algebraic Approach Window For Pinion