SELECTION OF MATERIALS FOR CUT TOOLS OF MOTORIZED MANUAL WEEDER FOIL

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Abstract: The selection of materials for cut tools is a complex task, because besides a high number of materials, the environment and the work conditions are quite varied. The focus of this work is the cut tools of motorized manual weeder foil, rotative tools used in the effective cut of the dense vegetation. Such tool is subjected to the constant impact with different objects than she enters in contact during the cut (ground, stones and tree stems). This generates superficial trines and subsequent break of the cut tool, harming the work and letting the operator susceptible to the accidents. In the present work will be used the Ashby Letters in the selection of materials for weeder foil cut tools with two tips, that are tools that present high income, however subjected the break. To reach this goal, went accomplished, analyses of the requisites of selection of the materials, determination of the critical properties of the material, selection of the candidate materials. The results showed that the methodology presents good results in the selection of materials for that cut tool type, as well as for other tools subjected to similar efforts.

Keywords: selection of materials, letter of Ashby, cut tools of weeder foil, impact resistance, flexing resistance

1. Introduction

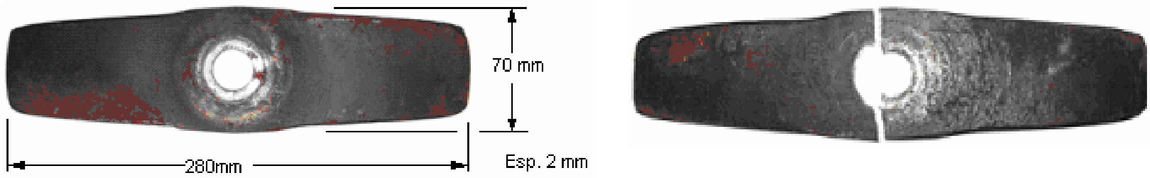
In agreement with Cury (1993), the engineers of industrial products have their disposition about 100.000 metallic alloys and a number similar of not-metallic materials. The number high of materials must also be combined to the high number of fabrication processes of the products. Therefore, an engineer has a great universe of possibility of materials and processes for the development of products.

Forcellini (2004) explains that if a material is selected inadequately, this can take so much to the flaw of a component as the presence of unnecessary costs. Therefore, the selection of materials is the choice of the material that has the best performance at the smallest cost. Thereby, the process of selection of materials, in the stage of the project of the product, is of substantial importance to the success of a product during its functional performance in its life cycle.

In this work, aspects regarding the selection of materials for cut tools used in motorized manual weeder foil will be presented. Such tool is called of blade. It was verified, through the research accomplished with users of weeder foil of the middle-west region and of the plateau region of the State of Santa Catarina, which the work is accomplished in adverse conditions, such as: wavy land, stony, with tree stems and other obstacles. This way, blade is submitted to several mechanical efforts, mainly at the impact for flexing.

The constant impact of the cut tool with objects of varied natures generates superficial trines and subsequent break of the tool. It was detected that such damages happen when the blade in high rotation, about 7.500 rpm, collides with stubs or stones. This had been caused serious work accidents when eventual, but considerable pieces of the cut tool collide in the machine operator. Users' reports confirm that the feet and the legs are the parts of the human body which more frequently are hit.

The most serious accidents happen in hard works, where there are many stubs and stones, for example, in the selective in *pinnus* reforestation and in the cleaning of naturalized native countryside. In these conditions the cut tool suffers a lot of impacts for work day. The Figure 1 shows some characteristics of blade for motorized manual weeder foil collected in countryside.



(a) (b)

Figure 1. Blade for weeder foil collected in countryside, in normal state (a) and broken (b).

For complement and base the problem, sample of broken blade were analyzed through visual analysis of fracture and analysis of hardness Rockwell in scale C, according with NBR 6671. In the visual analysis it was identified through the fractures, in reference Colpaert (2000), that the fractured material is fragile and that the blade is manufactured in steel-carbon. In the mechanical analysis of hardness the cut tools presented superficial medium hardness of 60 HRC (Rockwell C). In agreement with Chiaverini (1986), hardness above 60 HRC are considered high in pieces of small thickness (sheets) which being submitted at the mechanical efforts of impact.

Considering what was presented, the proposed exercise will be find the most appropriate material blade used in motorized manual weeder foil. The systematic used in the work was in reference Ashby (1992) and Forcellini (2004), and the proposed problem is one of the needs presented by the users of motorized manual weeder foil.

2. Process of Selection of the Material

In reference the Ashby Letters (1992) and in the process of selection of materials extolled by Forcellini (2004), that he considers that the problem is of many variables and solutions, because it depends on the properties of the materials, of the production process and of the project of the component, the process of selection of materials is composed by the following stages which will be executed:

(1) Analysis of the requisites of selection of the materials: they are determined the service conditions and the environment that the product should support;

(2) Determination of the critical properties of the material: in function of the service conditions and environment, verified which conditions determine critical properties of the material and which are their maximum and minimum values;

(3) Selection of the materials candidates: the critical properties are compared with the properties of the materials of a database, through the use of the Ashby Letters (1992);

(4) Selection of the material candidate: the materials are analyzed in terms of product performance, cost, easy production, availability and mechanical resistance. In this case it will be used the multi-criteria method;

1ª Stage: Determination of the selection requisites of the materials in reference at the service conditions, environment, the consumer's desires and at the life cycle of the product.

As presented in the problem, they were identified the following service conditions and environment of work in which the cut tool is subjected:

- Impact with stones, tree stems, ground and with the own vegetation;
- Flexing effort of the cut tool due to the force reactivates of shearing of the vegetation and occasionally with other obstacles;
- The environment of work with superficial irregularities, such as: slopes, acclivities and undulations;
- Vibrations in the blade provided of its unbalanced, in function of its partial break and the high work rotation.

2ª Stage: Determination of the critical properties of the material. In reference the conditions and environment of work of the cut tool, they are verified which the condition that determine the critical properties of the material and, which are the maximum and minimum values of these properties.

In agreement with Forcellini (2004), structural elements are component that carry out several physical functions and they must serve to requisites functional, geometric and of properties of the materials. The performance of a component, or also named performance "p", it can be written by the following relationship:

p = f [(functional requisites, F) (geometric parameters, G) (properties of the material, M)]

Or simply for the Equation (1):

$$p = f\,(F, G, M) \qquad (1)$$

The performance index "p", according to Forcellini (2004) it is characterized as a criterion of minimum mass, minimum volume, minimum cost, maxim rigidity, among others. Therefore, if the function aspects, geometry and properties of the material are separable, the relationship of the performance can be written according to the Equation (2):

$p = f1(F) . f2(G) . f3(M)$ (2)

As suggests Forcellini (2004) the procedure that derives the performance index follows eight steps. They are described and executed in the following:

The **first step** consists of identifying the attribute or criterion to be maximized or minimized. In reference the conditions and environment of work of the blade, some critical properties of the material were identified, that they must be maximized or minimized.

The impacts with stones, tree stems, among others, that they cause breaks or trines in the tool, it is require of the cut tool, impact resistance. The flexing efforts and shearing that the blade is submitted, due to the contact with the vegetation or other undesirable objects, require of the cut tool, hardness (traction resistance) to guarantee the function of cut of the vegetation. Therefore, the critical properties that the material must possess are the maxim mechanical impact resistance efforts and of flexing, in other words, the objective is to maximize the resistance module to the flexing for impact of the material.

The **second step** consists of developing the function criterion or objective function. In agreement with Goldsmith (1960), Johnson (1972), Graff (1975), and Stronge (2000) *apud* Malavolta (2003), a lot of impact situations exist. In the case of the blade for motorized manual weeder foil, that it suffers impacts with stones, tree stems, among other obstacles, this impact can be considered as rigid. This way it is possible the development of simple analytical methods to the determination of the tension of impact.

In analysis at the type of impact suffered for the blade, in agreement with their geometric and functional characteristics, the blade can be compared with a set beam, according to Figure 2.

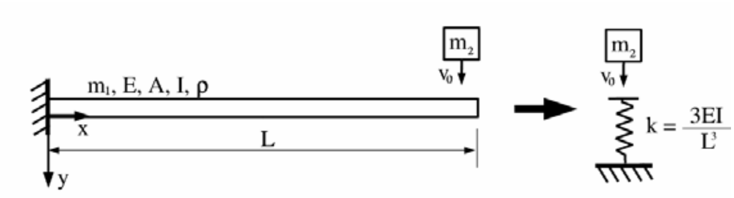


Figure 2. Traverse Impact in set beam - Goldsmith (1960).

The impact speed V_0 is relative to the different objects which collided with the tool. For the case of the blade, the mass, m_2, will be represented by the obstacles that will be stopped, since the relative speed of collision V_0, will be the tangent speed of the blade that can be expressed by the Equation (3):

$$V_0 = \pi \cdot \frac{L}{2}(m) \cdot n(rpm) \quad (3)$$

Where L is the length of the blade, in meters, and n the work rotation, in rotations per minute.

In agreement with Graff (1975), and Stronge (2000) *apud* Malavolta (2003), balance a swinging of the kinetic energy with the energy of elastic deformation, in the instant of maximum displacement, this can be expressed by the Equation (4):

$$\frac{m_2 \cdot v_0^{\,2}}{2} = \frac{K \cdot x_y^{\,2}}{2} \quad => \quad x_y = v_0^{\,2} \cdot \sqrt{\frac{m_2}{K}} \quad (4)$$

The maxim tension will happen where the flexing moment M_f is also the maximum, and for the proposed case of the cut tool it can be expressed by the Equation (5):

$$\sigma_{Max} = \frac{M_f}{W_f} \quad => \quad \sigma_{Max} = \frac{P \cdot L}{W_f} \quad => \quad \sigma_{Max} = \frac{K \cdot x_y \cdot L}{W_f} \quad (5)$$

Where:

$\sigma_{Máx}$ = Maximum Tension (Pa);
Mf = Flexing Moment (N.m);
Wf = Flexing Resistance Module (m^3);
P = Impact Force = K.xy (N);
K = Rigidity Coefficient of the Elasticity of the cut tool ($K= 3EI/L^3$);
V_0 = Impact Speed (tangent speed of the cut tool - m/s);
E = Elasticity Module (N/m^2);
I = Inertia Moment (m^4);
L = length of the cut tool (m);

x_y = Displacement caused by the flexing impact (mm).

The **third step** consists of identifying the free variables from project, in other words, the ones that can vary freely. In ownership of the project equations of the equipment, to identify which the variables are that can be modified without restrictions. For this case appraised, the variable free to be considered is the displacement caused by the flexing impact, x_y, to which varies freely when executed a work. Another variable free to be considered is the relative speed V_o, that is given in function of the rotation of the weeder foil, that can vary freely during the execution of a work.

The **fourth step** aims at to identify the restrictions and its importance order. As already mentioned in the presentation of the problem, hardness similar or superior to 60 HRC, turn the blade vulnerable to trine and breaks, when it is submitted to the impact efforts, committing the users' safety. However, in agreement with Chiaverini (1986), if the hardness is inferior to 40 HRC, the ductility increases in the material, facilitating thus its plastic deformation. For the case of the blade that possesses a refined thickness (approximately 2 mm), a flexing of the same during the execution of a work, would cause a significant loss of its capacity of cut. As the hardness is directly proportional to the resistance the traction of the material, it is had as restriction of the project, in agreement with the chart of conversions of hardness, a traction resistance among 1300 N/m^2 (40 HRC) and 2300 N/m^2 (60 HRC). In agreement with Chiaverini (1986) the maximum tension ($\sigma_{Máx}$) applied in a machine element it must not cross the limit of the tension of yield of the material (σ_t). As $\sigma_{Máx}=0{,}45.\sigma_t$, and also aiming at the weeder foil users' safety, the tensions to be taken into accounts will be between 585 and 1035 N/m^2. Thus, so much the traction resistance of the material, as the module of elasticity of the material, they must be in balance to the blade to resist to the impacts and to guarantee the users' safety. In agreement with previous identification of the material, sample of a weeder foil cut tool manufactured in steel, the module of elasticity of the material, *E*, it must be in close values approximate of the steel, in other words, *E = 210 GPa.*

The **fifth step** consists of developing the restriction equations. With the aid of specific equations of mechanical dimensioning, they are developed the restriction equations that represent the values limits for some parameters, in order to avoid every type of functional flaw and of material of the system to be developed. For the case of the blade and in reference the Equation (5), arrived the Equation (6):

$$\sigma_{Max} = \sigma_f = \frac{K \cdot x_y \cdot L}{W_f} \tag{6}$$

The **sixth step** aims at to substitute the free variables from the restriction equations in the function criterion. Once identified the free variables from the restriction equations, these should be substituted in the function criterion, in order to make possible the correct selection procedure.

Isolating the free variable (x_y) of the Equation (6) it is had the Equation (7):

$$x_y = \frac{\sigma_f \cdot W_f}{K \cdot L} \tag{7}$$

Being equal the two flexing values, x_y, of the Equation (4) and Equation (7), it is had the Equation (8):

$$\frac{\sigma_f \cdot W_f}{K \cdot L} = v_0 \cdot \sqrt{\frac{m_2}{K}} \quad => \quad W_f = \frac{v_0 \cdot K^{\frac{1}{2}} \cdot L \cdot m_2^{\frac{1}{2}}}{\sigma_f} \tag{8}$$

As $k = \frac{3 \cdot E \cdot I}{L^3}$, then:

$$W_f = \frac{v_0 \cdot \left(\frac{3 \cdot E \cdot I}{L^3}\right)^{\frac{1}{2}} \cdot L \cdot m_2^{\frac{1}{2}}}{\sigma_f} \quad => \quad W_f = \frac{3^{\frac{1}{2}} \cdot v_0 \cdot E^{\frac{1}{2}} \cdot I^{\frac{1}{2}} \cdot m_2^{\frac{1}{2}}}{\sigma_f \cdot L^{\frac{1}{2}}} \tag{9}$$

The **seventh step** consists of group the variables according to the Equation (2). The variables must be contained in three groups: functional (F), geometric (G) and properties of the materials (M). Promoting the due adjustments in the Equation (9), it is had the Equation (10):

$$W_f = \left[v_0 \cdot m_2^{\frac{1}{2}}\right] \cdot \left[\frac{I^{\frac{1}{2}}}{L^{\frac{1}{2}}}\right] \cdot \left[\frac{E^{\frac{1}{2}}}{\sigma_f}\right] \tag{10}$$

Where:

$\left[v_0 \cdot m_2^{\frac{1}{2}} \right]$ It's *corresponds to the functional parameters, F.*

$\left[\dfrac{I^{\frac{1}{2}}}{L^{\frac{1}{2}}} \right]$ It's *corresponds to the geometric parameters, G.*

$\left[\dfrac{E^{\frac{1}{2}}}{\sigma_f} \right]$ It's *corresponds to the parameters related to the properties of the materials, M.*

The presupposition of the independence of the project factors brings a great simplification, because the performance of the functional and geometric factors is optimized with the maximization of the material factor (FORCELLINI, 2004). That group of actions is known as method of the performance index. The procedure to maximize the performance index is detailed best in Ashby (1992).

The **eighth and last step** consists of identifying the performance index, expressed for the property M, to be optimized. It corresponds to the parameters related with the properties of the materials, and the best material for production of blade will be one that to present larger value of M, given by the Equation (11):

$$M = \frac{E^{\frac{1}{2}}}{\sigma_f} \qquad (11)$$

Therefore the performance index M is the function to be maximized for the cut tool to have resistance maxim to the impact for flexing without affecting its function of cutting the vegetation. It is noticed that the module of elasticity of the material (E) it should be maximized and the tension (σ_f) it should be minimized. However, there are restrictions of the minimum values of σ_f, like presented in the fourth step.

3ª Stage: It involves the accomplishment of a selection with the objective of selecting materials candidates, using a database (Ashby Letters) and in reference the critical properties of the materials of the prior stage.

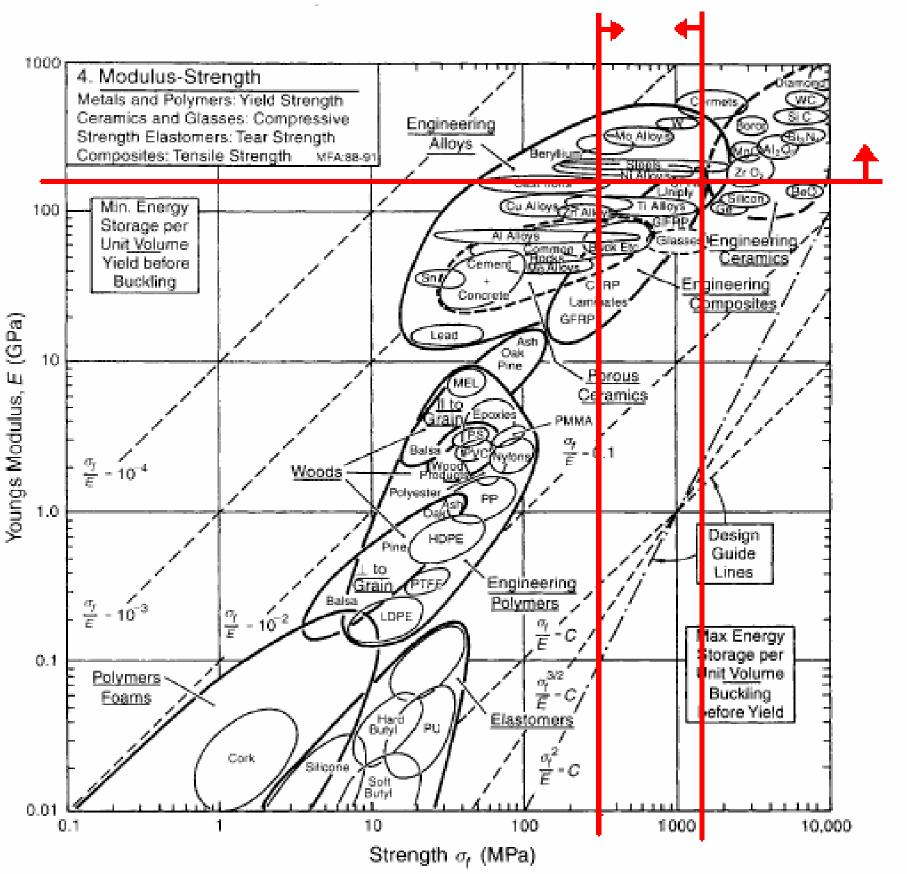


Figure 3. Letter 4 - Module of Elasticity x Tension Limit of Yield (ASHBY, 1992).

In this work, the performance criterion is to maximize the impact resistance for flexing of the blade. In this case the Letter of Selection of Materials 4 was used - Module of Elasticity x Tension Limit of Yield, it is represented by the Figure 3. The lines drawn on the letter describe the values of the restrictions in reference at the values presented in the fourth step of the 2ª Stage, and the arrows indicate for the areas of selection of materials.

It was verified through the Figure 3 that it exists various materials that can satisfy the requisites of project of the cut tool. Among them, they are mentioned: **steel alloys, cast steel, tungsten alloys, nickel alloys, molybdenum alloys, beryl alloys and CFRP** (Carbon Fiber Reinforced Plastic).

Firstly it was certain the index of importance of each property, according to Table 1.

4ª Stage: Identified the materials with potential of assisting the exigencies of the problem, it should to select the material candidate. The multi-criteria method, it is proposed by Forcellini (2004), was used to select the most appropriate material. In this stage, the materials were analyzed in terms of cost, easy production, availability, fatigue resistance and fracture tenacity.

Firstly it was determined the index of importance of each property, of accord with the Table 1.

Table 1. Determination of the index of importance of the properties.

Properties and Interrelations	1 1-2	2 1-3	3 1-4	4 1-5	5 2-3	6 2-4	7 2-5	8 3-4	9 3-5	10 4-5	Σ	ω
1- Cost	1	0	0	0							1	0,1
2- Easy production	0				1	0	0				1	0,1
3- Availability		1			0			0	0		1	0,1
4- Fatigue resistance			1			1		1		1	4	0,4
5- Fracture tenacity				1			1		1	0	3	0,3

Later, each material received a certain value in reference their properties. Such value possesses the following weights: Bad (0), Regulate (25), Satisfactory (50), Good (75) and Excellent (100). The multiply between each value and the index of importance of each property (ω), generated a total balance for each material. The consideration of the materials was in reference at catalogs of manufacturers of materials (Aços Gerdau and Aços Villares), information contained in the site www.efunda.com and in Ashby (1992). The material selected was that one which obtained the larger balance.

Table 2. Final Selection of the material for blade of motorized manual weeder foil.

Properties	ω	Steel Alloys	Cast Steel	W Alloys	Nickel Alloys	Mo Alloys	Beryl Alloys	Carbon Fiber
1- Cost	0,1	75	100	25	25	25	25	50
2- Easy production	0,2	100	50	75	75	75	25	25
3- Availability	0,1	100	100	75	50	50	25	75
4- Fatigue resistance	0,2	75	50	100	75	100	75	100
5- Fracture tenacity	0,4	100	50	75	75	75	50	50
TOTAL		**92,5**	**60,0**	**75,0**	**67,5**	**72,5**	**45,0**	**57,5**

Through the Table 2 it was verified that the steels alloys satisfy better the conditions service of the cut tool, considering aspects like the cost, easy production and availability of the material.

The tungsten alloys, nickel and molybdenum would also be good options in what says respect to the resistance the fatigue and the fracture; however aspects as availability and easy production impede them for the use. The carbon fiber possesses good resistance to the fatigue; however it is impossible to use it, in function of the blade geometry, refined thickness (2 mm) and because of the material not to possess good resistance to the impacts with rigid objects and with high-speeds.

3. Conclusion

It was verified that this systematic and the Ashby Letters were quite useful in the selection of the most appropriate material for the production of cut tools for motorized manual weeder foil, also being able to this methodology to be used in the selection of materials of other cut tools or components with similar application.

The steels alloys had already been used with this purpose, for that reason for the result was already waited. For such, it suggests itself, as subsequent stage, the choice of the commercial class of the steel-alloys that best satisfies the limits of the properties that the blade must possess.

It is worth to emphasize that other aspects must be considered in the project of such tool, like for example, the production process of the blade and the possible heat treatments that will be utilized. It suggests itself for such, that it be accomplished an analysis of optical spectrometry of the material that now it is manufactured the cut tool and an analysis micro-structural of the cut tool, with the objective of identifying the nomenclature or class commercial of the material and the type of crystalline structure of the blade. Thus, they can be proposed changes in the project of the tool, like for example, in the production process and / or in the cut tool geometry.

Experimental tests and analyses by finite elements also suggest which be accomplished, for to verify the mechanical properties of the product and to obtaining reliable statistical data regarding the applied efforts on the product.

Therefore, for the selection of materials in the stage of project of products, some factors must be analyzed as: the function and the geometry of the product, the efforts which are applied on the product, involved costs and the production process. Other aspects which are related at the use with safety, government normative requisites referring to the environment, they also must be considered in the process of selection of the materials.

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