

EDGE MACHINABILITY OF MDF EFFECT ON SURFACE QUALITY AND CONSEQUENCE FOR GLUING

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Abstract

MDF is becoming the basic wood-based material used in the furniture industry. The main goal of the research is the improvement of the machining process to produce edge surfaces with the required quality for a high gluing toughness.

The fracture energy ratio (G1c) is measured using cantilever beams samples and the results are analyzed to qualify the toughness of two planed MDF panel edges glued together.

The chip thickness effect on G1c is clearly demonstrated by the experiments. Here, it is possible to find a linear relationship between G1c and surface roughness criterion (Ra). The allowed chip thickness is limited by the industrial milling conditions.

We can conclude that the chip thickness in the range 0.20 up to 0.35 is the most significant parameter for a high performance gluing.

Keywords: Machinability, M.D.F., Surface quality, Gluing.

Résumé

Le MDF (Medium Density Fiberboard) est l'un des panneaux à base de bois le plus utilisé dans le secteur de l'ameublement. L'objectif principal de cette étude est de définir des conditions de coupe optimales permettant d'obtenir des chants donnant un collage aux caractéristiques mécaniques maximales. Le taux de restitution d'énergie (G1c) est mesuré au moyen d'échantillons à travers l'essai habituellement utilisé dans la mécanique de la rupture « DCB » Double Cantilever Beam. L'analyse des résultats obtenus permet de qualifier la résistance des échantillons de MDF collés deux à deux. L'effet épaisseur du copeau est clairement mis en évidence dans nos essais. De plus, il est possible de trouver une liaison linéaire entre G1c et le critère de rugosité Ra, l'épaisseur du copeau étant limitée par les conditions de coupe industrielle.

Nous concluons que l'intervalle d'épaisseur du copeau 0.20 à 0.35 mm est le paramètre le plus significatif de l'usinabilité pour une haute performance de collage.

Mots clés: Usinabilité, M.D.F., Qualité de surface, Collage.

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ملخص

MDF من المواد الخشبية الأكثر استعمال في ميادين الأثاث معروف أن هو منظم.... صناعته تظهر وجه غير متجانس من ناحية الكتلة في نواحي السمك. الشيء الذي يعطي نوعية التقطيع في الحال حيث يكون الوجه الداخلي أفضل من الوجه الخارجي.

إذن الهدف الأساسي لهذا البحث أنه يشمل على تصنيف شروط القطع المتميزة التي تعطي حلول التصاق ذات الميزة الميكانيكية المرتفعة النسبة لإسترجاع الطاقة (GNC) موزون بإستعمال مواد عن طريق التجربة المعتادة المستعملة في ميكانيك التحطيم (DCB). تحليل النتائج المتحصل عليها تمكننا من مقاومة النموذج لـ (MDF) متلاصقة مثني مثني.

بفعل سمك المتوسط للرائش (EM) الواضح في التوضيح الكامل عبر تجاربنا زيادة, من الممكن أن يتبين لنا إيجاد علاقة مستقيمة بين (GIC) مع الخشونة R_a . المتوسط للرائش هي محصورة بشروط القطع الصناعي. نختم أن الفاصل سمك المتوسط للرائش (E_n) من 0.20 إلى 0.25 هو الموصف الأكثر تمييز في التقطيع أو هيئة السطح المقطع للإلتصاق المتميز.

الكلمات المفتاحية: التقطيع MDF نوعية السطح, الإلتصاق.

Over the last few years the production of MDF (Medium Density Fiberboard) has been gaining in importance on the panel market.

Whereas MDF accounted for 20% of total panel consumption in Germany and Italy during 1990, the corresponding figure for France was Only 2 % over the same period. In 1990, 200,000 m³ of MDF were produced in France while domestic demand doubled from 45,000 m³ in 1989 to 90,000 m³ in 1990.

Information available on trends for the short term suggest that domestic demand will increase steadily. As is the case with all new materials, the processes employed for conditioning and processing MDF must be optimised. Despite its isotropic nature, the product is structurally heterogeneous throughout, thus making it comparable to a laminate material in this respect. This heterogeneous structure may lead to difficulties in machining the edges of the product, and these will in turn directly affect subsequent operations (finishing treatment, gluing, etc.). The aim of this study is therefore to define in a realistic way what the optimum cutting conditions are for producing edges which give a bond of maximum mechanical strength when such edges are produced by a conventional machining method involving chip removal.

1- EXPERIMENTAL PROCEDURE

1.1- General procedure

The experimental procedure which was adopted is illustrated in the following diagram (Fig.1) [1].

The measurement of the surface quality produced simply links the production requirements and the mechanical performance of the glued

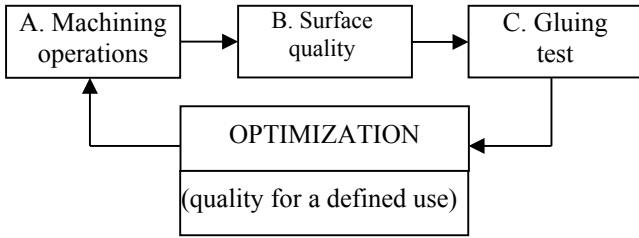


Figure 1: Optimization diagram.

joint. The condition of the surface is the easiest quality parameter to check against the product and at the outlet of the machine.

The parameters which are involved in edge machining are confined to the following:

- cutting mode (cutting carried out parallel and counter to the direction of the tool)
- type of tools (HSS and K20 carbide) with a variable cutting angle
- cutting conditions in terms of average thickness of the chip (E_m).

The entire experiment was carried out using a sample which was considered to be homogeneous and which had been taken from a single panel off the production line. The entire experimental Procedure is illustrated in figure 2. The moisture content of the panel is the only variable which was taken into account as regards the machined Material. This variable should reflect the storage conditions which apply to applications on an industrial scale.

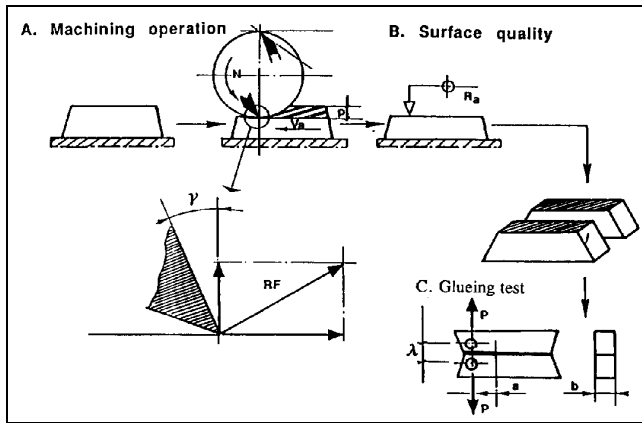


Figure 2: Experimental process.

1.2- Machinability of MDF

The machining test bench [2] illustrated in figure 3 was used to determine the suitability of basic wood-based for machining purposes by means of:

- the cutting effort or the electric power consumption;
- the tool's level of wear and the characteristics of the chips produced.

These three criteria were adopted owing to their importance in terms of production costs and the machine's environment (collection of chips, hygiene, energy costs, etc.). The results will be expressed either in terms of cutting effort or electric power since it has been possible to show that there is a perfect linear correlation between these

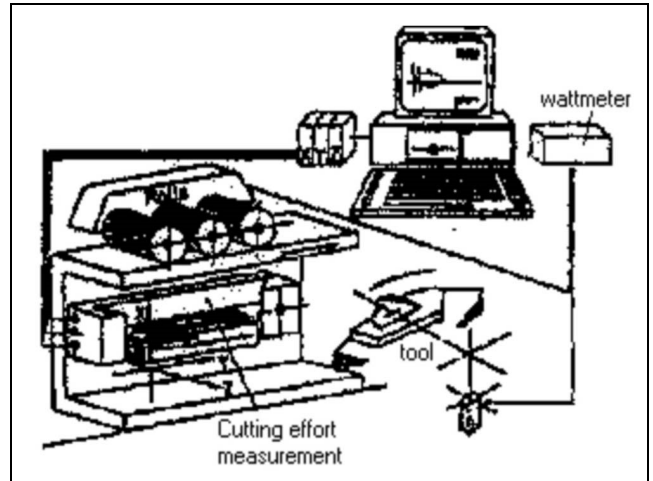


Figure 3: Equipment.

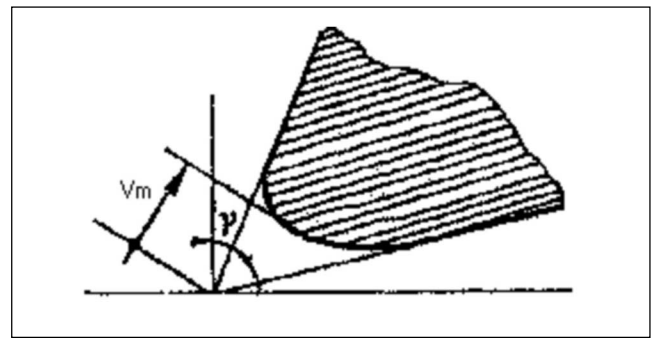


Figure 4: Tool wear characteristic.

two criteria. The wear of the tool is conventionally characterized by the displacement of the cutting edge due to wear V_m (Fig. 4) as measured on a profile projector - this factor can only be taken into account for HSS tools owing to the low degree of wear experienced by carbides.

The process by which the chip is formed is tackled by classifying the chips according to 5 basic types, namely, type 1, the basic chip produced by edge milling; type 2, the wafer chip produced by ungluing the particles on the faces in particular; type 3, the finished thickness strip chip; type 4, the arc chip, and lastly the type 5 dust.

Once the requisite surfaces have been obtained, the quality of the machining carried out is quantified by measuring surface roughness by two methods:

- measurement by mechanical tracing using a profile measurement bench with systematic calculation of parameter R_a , which has been used in this study as the standard criterion and which is illustrated in figure 5,

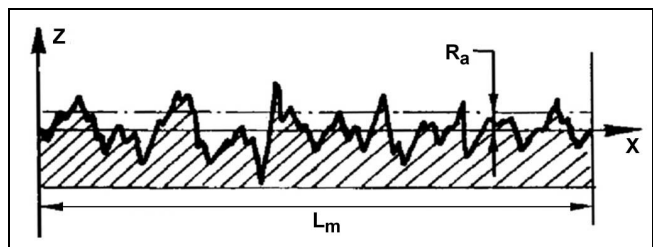


Figure 5: Surface description using R_a parameter.

- measurement by artificial imaging using a video camera and rim lighting. The criterion adopted in this case is the standard deviation "SD" of the levels of Grey measured using a linear profile as in the case of measurement by the tracing method; however, this criterion is not discussed in this document since it was nearly used to bring into line the results obtained by mechanical tracing [1].

1.3- Mechanical characteristics or the glued joints

The rate of energy restoration G_{1c} was measured by the compliance method which has already been used by a number of authors [3-5] for characterizing glued joints. In general terms this method consists in measuring the compliance variation of the specimen which is glued and split in the glue joint, with the initial length of the defect being introduced artificially by the absence of glue in the joint.

G_{1c} is given by the expression :

$$G_{1c} = \frac{P^2}{2b} \frac{\partial c}{\partial a}$$

where C is the compliance of the specimen (type DCB), $C=f(a)$ in the form $C=A.exp(Ba)$ is determined experimentally ($C=\lambda/p$), and P , is the critical load which causes the start of the split (deviation from linearity on graph $P=f(\lambda)$). Only the fracture mode (I), the split lip opening mode, has been used.

This mechanical quantity G_{1c} makes it possible to characterize the wood/glue relationship in general terms. The only variable is therefore the surface quality of the glued MDF edge. The samples, which were machined under the same conditions and exhibited the same surface characteristics, were planed in order to produce the DCB type mechanical fracture specimens (Fig. 2). The joints were produced using vinyl glue under 1.5 MPa at 30°C. The average thickness of the glue joints obtained was 0.15 mm. Duchanois [6] has shown that over this range (0.1 - 0.2 mm) $G_{1c} = \text{constant}$.

2- EXPERIMENTAL RESULTS

2.1- Machinability of MDF

All the figures given below (Fig.6) define the main characteristics of MDF from the point of view of its suitability for machining; these figures are expressed in terms of total cutting effort RF , or electrical power consumption ($RF=f_i(P)$ $r^2=0.98$ *** for all the test), as a function of:

- moisture content of the panel (related to storage conditions) : I,
- density of the panel (related to the variability of the material) : II,
- the cutting angle (related to the machining conditions) : III,
- the average thickness of the chip E_m - this reflects, in the form of a single parameter, the machinability of the panel and provides a means of not having to cater for the hidden variables introduced by any variation in one of the industrial cutting parameters (spindle speed, feed rate, depth of cut, etc.) : IV.

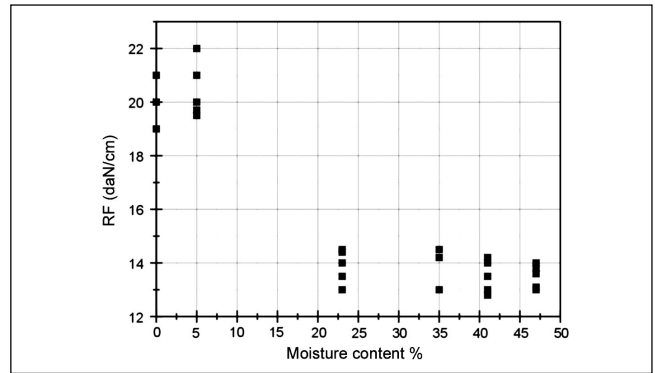


Figure 6.1: Variation of total cutting effort with moisture content conditions.

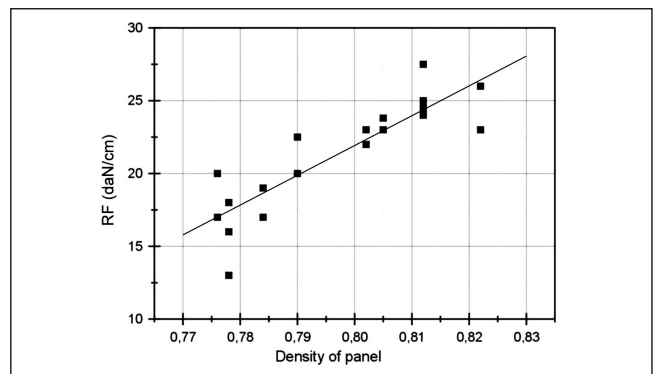


Figure 6.2: Variation of total cutting effort with the density of panel.

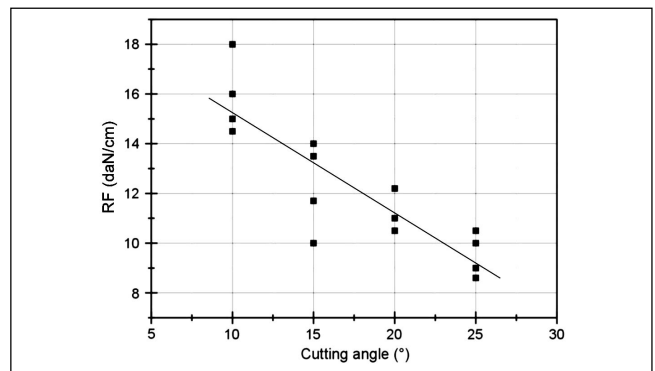


Figure 6.3: Variation of total cutting effort with the cutting angle.

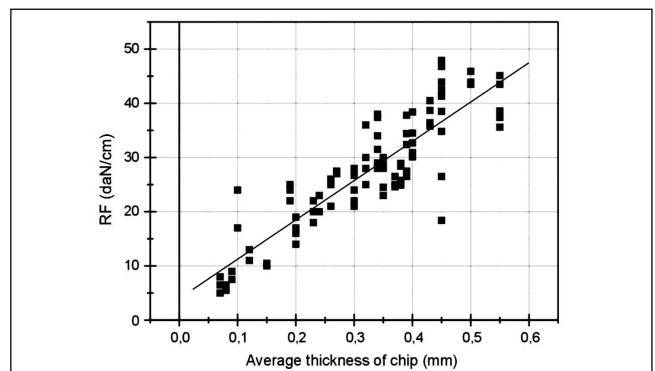


Figure 6.4: Variation of total cutting effort with the average thickness of chip.

Figure 6: Variations of cutting effort Vs. Different parameters.

The tool wear measurements carried out on tool HSS confirm that the conventional results obtained with panels apply to MDF as well [7]. However, in this study it has been possible to highlight a measurement of wear or displacement of the cutting edge due to wear by monitoring electric power. These results are illustrated in figure 7.

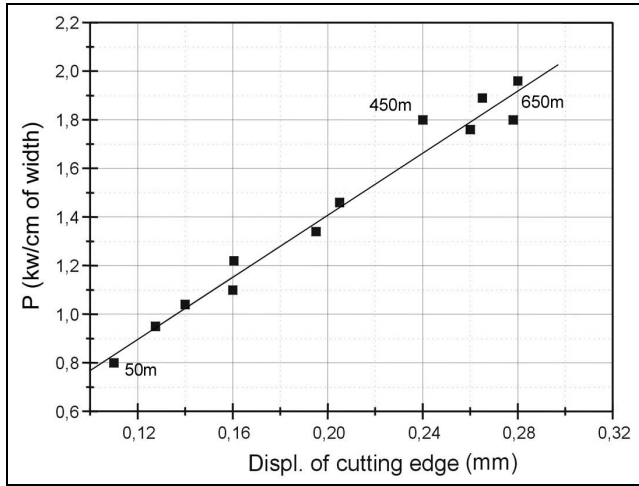


Figure 7: Relation between tool wear and electric power.

In the case of all the tests carried out, the characteristics of the chips produced have been systematically recorded using the nomenclature described in section 1.2. In this nomenclature [1], two categories of chip are to be avoided, types 2 and 3, which are heavy chips which pose problems as regards suction power and also attendant difficulties with regard to removal; and type 5 (dust), for reasons associated with the operator's environment and on hygiene grounds. The following table (Tab.1) shows the results obtained, (C= machining of the edges, F= machining of the faces). What results is a set of cutting conditions with which acceptable chips can be produced. These cutting conditions are expressed in terms of average chip thickness and are mainly within the range (0.16 - 0.30 mm).

N (tr/mn)	Va (m/mn)	P (mm)	Em (mm)	Type of chip (C)	Type of chip (F)
6000	3	5	0.04	5	3
6000	15	1	0.10	5	3
8000	15	5	0.16	4	3
6000	15	5	0.22	4	3
4500	15	5	0.29	1	3
6000	23	5	0.33	5	2
6000	15	13	0.35	5	2
3000	15	5	0.43	5	3

Table 1: Type of chip formation cutting parameters.

2.2- Description of the machined surfaces

All the surfaces machined under the cutting conditions described above are characterized by mechanical tracing according to the single criterion *Ra* (mean arithmetic deviation of surface roughness in relation to the average line [8]) (Fig.5).

This description of surface characteristics, or measurement of surface roughness, links up the production

of the surface (machining of the edges) and the application (gluing of the edges).

All the results are illustrated in the following figure (for a carbide tool) (Fig.8), once again expressed on the basis of the single parameter *Em*.

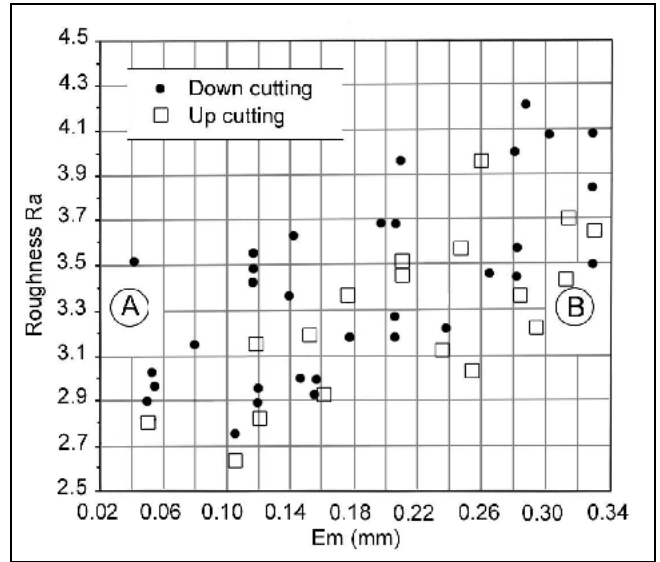


Figure 8: Variation of surface quality vs. average chip thickness. A and B are extreme cutting conditions:

A: N=5000 tr/mn, Va=3 m/mn- B: N=3000 tr/mn, Va=15 m/mn.

The best surface condition in terms of *Ra* (minimum *Ra*) is obtained with the minimum values for the average thickness of the chip and by down milling machining.

A visotactile assessment of the machined surfaces within the range of cutting Conditions described above was carried out.

This manual method does not make it possible to classify the surfaces qualitatively from an objective point of view (from smooth to rough). This could only be done by means of mechanical (or optical) measurement of surface roughness.

2.3- Mechanical performance of the glue joint

The quality of the joint in a glued bond depends on the glue used, the conditions under which it is employed, and the nature and quality of the substrate. The surface topography or roughness is an important factor as regards the quality of adhesion [9]. Although the effect of surface roughness on the fracture energy of glued wood/wood joints has already been highlighted by many authors [10], there are no such results for MDF. Figure 9 shows the changes in mechanical characteristics expressed in G1c.

Despite a considerable spread in the values, there is a linear correlation between surface roughness and the mechanical characteristics of the joint.

A surface degradation of 1 on the *Ra* scale results in an increase in fracture energy of nearly 40%.

This result is confirmed by all the tests carried out (machining carried out parallel or counter to the direction of the tool, variation of the cutting angle and different types of tool). The variability of the results can in part be explained by the nature of the fractures (cohesive or adhesive

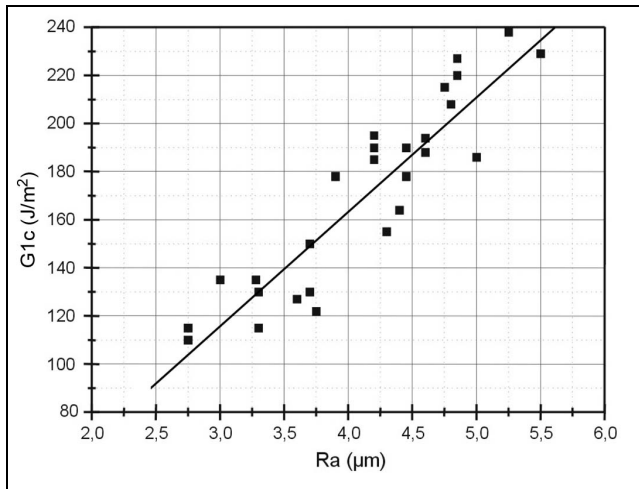


Figure 9: Fracture energy vs. surface roughness (different cutting angles and tool types).

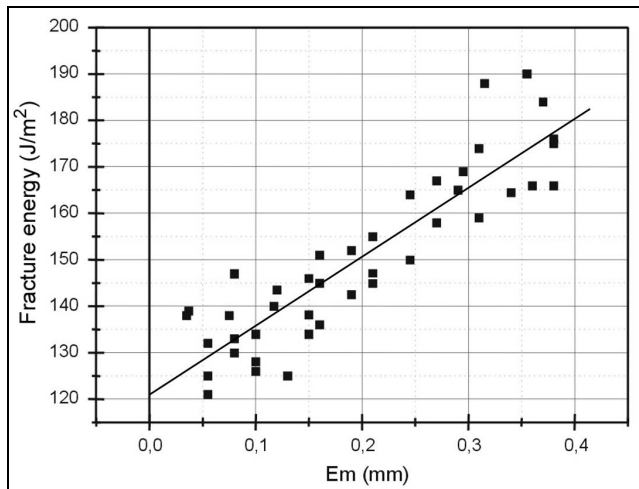


Figure 10: Fracture energy vs. average chip thickness.

fractures). Rather than clarifying the role played by each of the various machining parameters (up or down), the quality of the bond is directly related to the average thickness of the chip. Figure 10 illustrates these results.

It is of vital importance that the surface condition criterion for a given machining operation be defined on the basis of the application in question (gluing, finishing treatment, etc.).

There is no point in trying to come up with a smooth surface at any cost. Although in the case of metallic or allied materials the surface condition criteria characterize surfaces at which friction occurs, this is not the case in this instance with MDF surfaces (on edges), where a high degree of surface roughness is, required for bonding purposes. This surface roughness is limited to the 3rd and 4th order deviations and, of course, to the deviations in shape : surface evenness and waviness (1st and 2nd orders) are still to be minimized in order to improve the quality of the bond and avoid the maximum permissible joint thickness for a given adhesive being exceeded at the interface.

In the final analysis, this linear relationship $G1c=f(Em)$ provides a means of determining the optimum cutting conditions for producing MDF edges which are amenable to gluing.

CONCLUSION

This study highlights the relationships which exist between quality (illegible) of surface characteristics and the uses to which the surface in question are put (for a particular manufacturing process). It is in this connection that matching up surface quality and applications becomes fully meaningful, since trying to produce a surface of the highest possible quality (low surface roughness) means a minimum level of mechanical strength when MDF edges are being glued - a rough surface means a higher fracture energy for the bond planes. The single parameter Em , the average thickness of the chip, provides a means of correctly describing all the machining parameters - although there is a linear relationship between the average thickness of the chip and the fracture energy of the glued joint, this relationship is limited by what conditions can realistically be achieved during manufacture which, in the present case, involves machining edges within the range ($Em = 0.2/0.35$ mm) (for a tool diameter of 160 mm). In this context, machining carried out under optimum conditions (for producing chips) makes it possible to produce glued joints with optimum mechanical characteristics.

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