Improving the facade element surface processing of MDF case furniture

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Abstract. A lot of enterprises engaged in the production of MDF case furniture face the problem of milled plate surface quality. It ensures the production of facing paper and synthetic film or finishing liquid paints and varnishes to improve the facade element surface processing quality of MDF case furniture. The experiments to study the roughness of MDF plates milled surface have been carried out, depending on the feed rate and tool rotation frequency. The work has been carried out using hard-face end mill tools manufactured in accordance with the patent for the utility model (Russian Federation), which enables to improve the quality of machined surfaces by performing finishing milling in one pass and increasing equipment productivity. The determination of the roughness parameter has been carried out in accordance with the requirements of 15612 State Standard. As a result of experimental processing, the dependences of milled surface roughness on the factors under study in the form of regression equations have been obtained. The mathematical dependencies are the results of this work. It enables to set regime parameters for profile milling of MDF surface plates to obtain the required roughness. The optimal milling mode has been determined improving surface finish facade element quality of MDF case furniture.

1. Introduction

The increased demand for individual design of case furniture, especially the facade (front) part of it, led to the search for a new material which could compete with solid wood and replace chipboard. These materials are medium density fiberboards [1, 2]. It has been able to occupy a niche in the Russian market. Now it is a popular construction material, the demand for which is constantly growing up [3].

Nowadays, the problem of the milled surface quality is especially acute in many enterprises engaged in the production of MDF case furniture. Since the specimens are subsequently used for facing with paper and synthetic films or finishing with liquid paints and varnishes, the surface roughness is one of the main indicators of MDF surface quality. The milled surface roughness is in the range from 60 to 64 µm while using standard mills. With such a roughness on the surface faced with decorative films there are defects in the form of depressions and degradations, shagreens (surface roughness), peeling of the film from the base, etc. The roughness of 20 µm or less is required to eliminate these defects. Bringing the roughness of the profile surface to such a value is currently performed by manual grinding. In addition, the reduction of the surface roughness requires frequent reshaping of cutting tool due to its rapid dulling.
To date, there is a significant amount of work by Russian and foreign researchers devoted to improving the processing quality of wood-based panel materials both by improving technological regimes and designs of cutting tools [4, 5, 6].

Based on the literature analysis, it has been established that the main parameters determining the amount of MDF milled surface roughness are feed rate, tool rotation frequency, angular parameters of the tools and plate density [7].

A number of studies are devoted to assessing the dependence of the milling surface roughness on the cutting energy [8, 9, 10].

Various types of cutting tool designs are used for wood material processing: solid cutters, hard-alloy reinforced milling heads with insert cutters, end mills, combined milling heads and others [11, 12].

There is a development of milling cutting tools, which provides the best accuracy and quality, the greatest flexibility of the technological process, while processing wood and wood materials. It creates the possibility of quick transition from processing workpieces of one size to processing workpieces of another size [13].

Gil V.I. has developed computational methods for determining the parameters of cutting conditions during machining the edges of medium-density fiberboard. The fatigue phenomena that occur in the milling tool have been investigated. Its performance has been predicted [14].

There is a method of milling plate wood materials, which increases the efficiency of aspiration, free exit of chips and dust from the cutting zone and reduction of energy costs for removing powder and dust from the cutting zone [15].

The Department of Mechanical Wood Technology and engineers of Trade Center «Mebel Chernozemya», LLC (Voronezh) have jointly developed a hard-alloy profile end mill for profile milling of MDF plate surfaces, which enables to improve the quality of surfaces processed by finishing one-pass milling and improve equipment performance [16, 17]. The proposed design of the tool enables not only to improve the quality of processing (the value of the surface roughness treatment is reduced from 60-64 to 18-20 µm), but also to increase the service life of the tool.

The aim of this work is to improve the quality of facade elements surface treatment for production of MDF case furniture due to improvement of technological modes.

2. Materials and methods
A series of laboratory experiments have been carried out to obtain mathematical models which are adequate to the actual process of MDF milling surface and to determine the influence of feed rate and speed of tool rotation on the roughness.

The experiment on the investigation of MDF milled surface roughness depending on the milling modes, consisted of two series of experiments on the treatment of MDF plate surfaces with carbide end mills manufactured according to the patent for a utility model No. 62059. In the first series, a blunt mill and a mill which is a subject to resharpening were used, which worked for a fixed period (7-8 hours). In the second series of experiments, a sharpened mill was used.

The research has been carried out in industrial conditions at «Mebel Chernozemya», LLC on the ROVER 22 software-controlled machine.

The uniform rotatable experiment planning method was used [18].

The varied factors were: tool rotation speed \( n \), min, and tool feed speed \( v_z \), m/min. The natural values of the factors were: for the first series of experiments: \( x_1 = 11\,000-15\,000 \text{ min}^{-1} \); \( x_2 = 1.0-8.0 \text{ m/min} \); for the second series of experiments: \( x_1 = 11\,000-15\,000 \text{ min}^{-1} \); \( x_2 = 1.0-5.0 \text{ m/min} \). The frequency of cutter rotation of 15 000 min \(^{-1} \) is the limit for MDF plates, since there is charring of the milling surface and vibration of the cutting tool at higher values.

The output indicator was the roughness of the plate milled surface \( R_z \), µm.

The planning matrices and the results of the experiment are presented in tables 1 and 2. These matrix data were implemented during an active experiment.
The constant factors were: angular parameters of the tool on the end and side planes – face angle $\gamma = 0^\circ$, cutting-point angle $\beta = 75^\circ$, back clearance angle $\alpha = 15^\circ$; cutter diameter $D = 40$ mm; plate thickness 16 mm; plate density 800 kg/m$^3$; type of the plate - unfaced medium density fiberboard; plate moisture content - 8 ± 2%; the plate was acclimatized in the workshop conditions at $t = 20 \pm 1^\circ$, humidity 60 ± 5%; binder content in the plate - 7 %; type of the binder - UF-LT-15 resin; the hardener content (ammonium chloride of 60% concentration) - 0.7 mass parts to the weight of the resin; species composition in the plate manufacturing is a mixture of pine/aspen/birch in equal parts.

The portable needle-type device Spectronic 10 was used to determine the roughness of the profile surface of MDF plates, which allows determining $R_z$ roughness parameter within 0.1–199.9 $\mu$m with an error not exceeding 5%. The determination of $R_z$ roughness parameter was carried out according to the requirements of 15612 State Standard.

**Table 1.** Planning matrix and the results of the experiment of the first series.

| № of experiment | Variable factors | Output parameter $y_1$ (roughness of the surface $R_z$, $\mu$m) |
|-----------------|------------------|-------------------------------------------------------|
|                 | Rotation speed, $x_1$ | Feed rate, $x_1$ | |
|                 | Coded values | Natural values, $10^3 \cdot$ min$^{-1}$ | Coded values | Natural values, m/min |
| 1               | -1           | 11.6          | -1           | 2              | 23.56   |
| 2               | +1           | 14.4          | -1           | 2              | 19.75   |
| 3               | -1           | 11.6          | +1           | 7              | 26.54   |
| 4               | +1           | 14.4          | +1           | 7              | 22.81   |
| 5               | - 1.41       | 11            | 0            | 4.5            | 25.69   |
| 6               | + 1.41       | 15            | 0            | 4.5            | 20.30   |
| 7               | 0            | 13            | - 1.41       | 1              | 21.21   |
| 8               | 0            | 13            | + 1.41       | 8              | 25.45   |
| 9               | 0            | 13            | 0            | 4.5            | 23.38   |
| 10              | 0            | 13            | 0            | 4.5            | 22.98   |
| 11              | 0            | 13            | 0            | 4.5            | 23.15   |
| 12              | 0            | 13            | 0            | 4.5            | 23.27   |
| 13              | 0            | 13            | 0            | 4.5            | 23.03   |

**Table 2.** Planning matrix and the results of the experiment of the second series.

| № of experiment | Variable factors | Output parameter $y_2$ (roughness of the surface $R_z$, $\mu$m) |
|-----------------|------------------|-------------------------------------------------------|
|                 | Rotation speed, $x_1$ | Feed rate, $x_2$ | |
|                 | Coded values | Natural values, $10^3 \cdot$ min$^{-1}$ | Coded values | Natural values, m/min |
| 1               | -1           | 11.6          | -1           | 1.6             | 23.07   |
| 2               | +1           | 14.4          | -1           | 1.6             | 19.04   |
| 3               | -1           | 11.6          | +1           | 4.4             | 24.59   |
| 4               | +1           | 14.4          | +1           | 4.4             | 20.96   |
| 5               | - 1.41       | 11            | 0            | 3              | 24.51   |
| 6               | + 1.41       | 15            | 0            | 3              | 19.29   |
| 7               | 0            | 13            | - 1.41       | 1              | 21.01   |
| 8               | 0            | 13            | + 1.41       | 5              | 23.21   |
| 9               | 0            | 13            | 0            | 3              | 21.84   |
| 10              | 0            | 13            | 0            | 3              | 22.16   |
3. Results and discussion

As a result of processing experimental data of two series of experiments, the dependences of the roughness of milled surface on the factors under study were obtained after processing the experimental data of the two test series ($y_1$ - roughness during blunt cutter processing, $y_2$ - when processing with sharpened mill, $\mu m$).

\[ y_1 = 23.26 - 1.898x_1 + 1.507x_2 - 0.081x_1^2 + 0.106x_2^2 + 0.02x_1 x_2 . \]  
(1)

\[ y_2 = 22.146 - 1.838x_1 + 0.775x_2 - 0.074x_1^2 + 0.032x_2^2 - 0.091x_1 x_2 . \]  
(2)

The adequacy of the model by the Fisher criterion is evaluated:

$F_{calc} = 3.04; F_{table} = 6.4.$

$F_{2calc} = 1.89; F_{table} = 6.4.$

In the exception method, the model is adequate if $F_{calc} < F_{table}$, therefore, the resulting models are adequate to the studied process.

Variable factors are in coded values in the resulting quadratic models. The quadratic models of surface roughness dependence $R_z$ on variable factors in natural values are:

\[ R_{z1} (n, v_s) = 31.941 - 0.317n + 0.372v_s - 0.041n^2 + 0.017v_s^2 + 0.006nv_s . \]  
(3)

\[ R_{z2} (n, v_s) = 29.481 - 0.187n + 1.056v_s - 0.038n^2 + 0.016v_s^2 - 0.046nv_s . \]  
(4)

As it can be seen from the equation (3), the largest amount in the absolute value is achieved by $b_2$ coefficient at $v_s$. And with an increase in $v_s$, the value of the response $R_z$ should increase. This means that increasing the roughness parameter is more influenced by the value of the tool feed rate. Parameter $n$ (tool rotation speed) and pair interactions $nv_s$ have smaller effect on $R_z$.

As it can be seen from the equation (4), the parameter $R_z$ has the greatest influence on the factor $v_s$, since the coefficient $b_2$ at $v_s$ is higher in its absolute value. And with an increase in $v_s$, the value of the response $R_z$ should increase. Parameter $n$ (tool rotation speed) and pair interactions $nv_s$ have smaller effect on $R_z$.

The influence of variable factors on $R_z$ parameter is studied through the obtained equations by constructing graphical dependencies, taking into account the ranges of variable factors (figure 1, 2).

The graphical analysis of the experimental results has shown that the surface roughness $R_z$, depending on the factors $n$ and $v_s$ under study, is parabolic in its nature. The graphs show that the value of the roughness parameter $v_s$ decreases with an increase in the tool rotation frequency $n$; and it increases with increasing feed rate $v_s$. A decrease in the surface roughness of the treatment is observed with an increase in the rotational speed from 11,000 to 15,000 min$^{-1}$ at a constant feed rate: for the first series of experiments by 19-23%, for the second series - by 20.9-21.6%. With an increase in the feed rate from 1 to 8 and from 1 to 5 m/min for the first and second series of experiments, respectively, the surface roughness of the treatment increases at a constant rotation frequency: for the first series - by 17.3-23.3%, for the second ones - by 10-11.1%.
A milling cutter (after a long period of operation time and requiring resharpening) was used in the first series of experiments. After processing, apparent presence of roughness of the sawn surface and fluffy sawn surface on the milled surface was noted, although the established change in the height of the irregularities is insignificant and does not go beyond the limits of one class. The occurrence of such surface defects indicates a strong blunting of the tool. By comparing the graphs, it can be concluded that the amount of tool bluntness affects the feed rate and, therefore, the quality of the resulting surface. Such a dependence of the surface roughness on the feed rate is a characteristic of both wood and chipboard plates. Similarly, the more blunted the tools are, the greater the impact of \( v_s \) is.

It is necessary to establish the values of the parameters determining the milling mode, which would enable to obtain the required surface roughness of MDF boards milling (R is not more than 20 μm).

The analysis of the graphs based on the results of experimental studies was carried out to determine the ranges within the rational milling parameters are.

![Graph a](image1.png)

**Figure 1.** The dependence of milled surface roughness on the tool rotation frequency: a - the first series of experiments, b - the second series of experiments.
Figure 2. The dependence of milled surface roughness on the feed rate: a - the first series of experiments, b - the second series of experiments.

With a tool rotation frequency \( n \) in the range of 14,000–15,000 min\(^{-1}\) and a fixed feed rate of \( v_s = 1 \) and \( v_s = 2 \) m/min (figure 1, a), the value of \( R_z \) is in the range of 20–18.44 μm. With \( n = 14,000-15,000 \) min\(^{-1}\) and a fixed feed rate \( v_s = 1; 1.6; 3; 4.4 \) m/min (figure 1, b) the value of \( R_z \) is 20-18.51 μm.

Figure 2 shows that the surface roughness does not exceed a value of 20 μm when changing the feed rate in the range of 1-4 m/min and constant rotation frequency \( n = 14400 \) and \( n = 15000 \) min\(^{-1}\).

Therefore, to obtain milling surface of the appropriate quality without reducing the performance of the equipment is possible with the following factor values: \( n = 14000-15000 \) min\(^{-1}\) and \( v_s = 1-4 \) m/min.
The search for the optimal technological mode of MDF profile milling was carried out using MiniMax computer program, written in Microsoft Excel.

The limitations of the optimization parameters are given taking into account the technological features of MDF plate processing and technical capabilities of machining center: 1 ≤ V ≤ 8; 11 ≤ n ≤ 15. Variation step for the parameters is 0.5. The process boundary conditions were specified: R_z ≤ 20 and R_z → min.

As a result, the optimal values of the technological parameters for the equations (3) and (4) have been obtained: tool rotation speed n = 15 000 min⁻¹; feed rate v_z = 1 m/min. The value of roughness is: 18.26 μm - for the first series of experiments, 18.508 μm - for the first series of experiments.

4. Conclusions
As a result of the work, aimed at improving the quality of surface treatment of the front elements of MDF case furniture, the experimental mathematical dependences have been obtained which enable to set the operating parameters for the profile milling of MDF surface plates to obtain the required roughness - not more than 20 μm. The optimum mode of milling MDF has been defined: 15 000 min⁻¹ - tool rotation speed; 1.0 m/min - feed rate.

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