CUTTING RESISTANCE OF MISCANTHUS PLANTS USING V SHAPED BLADES WITH OPENING OF 50 DEGREES AND DIFFERENT SHARPENING ANGLES

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Abstract. During the harvesting process of miscanthus plants, an important consumption of energy is given by the plants cutting resistance. In this paper there are presented a series of laboratory experimental research results regarding mechanical behaviour of plants during the cutting process using five V shaped cutting blades, with an opening of 50º and sharpening angles from 10 to 50º (with a step of 10º). The cutting resistance of miscanthus plants during the cutting process was determined by using a series of internodes distributed on the plants height and as a result it could be concluded that the lowest cutting resistance of the plant was seen for the superior internodes. The results presented in this paper can be useful to machine designers as well as miscanthus harvesting equipment builders/constructors, and also to specialists that work in the field of plant processing using their transformation in solid fuel, inclusive pellets.

Keywords: miscanthus stalk, V shaped blades, cleavage force, tangential stress.

Introduction

Renewable energy sources are nowadays more analyzed and searched for in the entire world. Biomass is one of these, worldwide being cultivated as numerous plants with high potential regarding the heating value and mass production.

The costs regarding culture establishment are damped by the fact that these cultures are in general perennial cultures, plant harvesting happens well after 10-15 years after planting and have minimum financial costs for maintaining.

It is necessary to improve plant harvesting and mechanical process for transforming biomass into an easy shape for using in thermal factories or for energy production machines. This assumes also cutting plants as drying, grinding, compacting biomass for obtaining pellets (with sizes bigger or smaller).

Mechanical resistance and plant behavior during mechanical processes are necessary to be known in order to design and make the cutting and grinding equipment.

Cutting and shredding equipment can be of various shapes and sizes, but the way they are design to function various very little from an equipment to another. Regarding the plant behavior during grinding, various tests were done worldwide, theoretical tests as well as experimental tests.

Thus, in paper [1] the authors studied the influence of angular speed, feed flow and the screen opening dimensions on the power necessary at grinding and also on the distribution after dimensions of the grinded material in rotary grinding equipment for various lignocelluloses materials. It was concluded that the power and energy necessary for grinding switchgrass increases proportionally with the angular speed of the hammer mill drum, but decreases (up to a certain limit) with the feed flow, disregarding the screen opening dimensions.

In paper [2] Tavakoli and other authors studied mechanical behavior at shear and bending stresses of two kinds of rice stalks with high humidity (70.8-71.6 %) for the first three internodes. They conclude that the shear endurance of rice stalks was of 8.56-13.08 MPa and shear energy consumption grew from the upper internode to the lower internode (from 122.76 MJ, to 236.06 MJ, for one kind of rice). Instead, Young modulus and bending endurance decreased from the upper internode to the third (from about 1.2 GPa to 0.4 GPa).

Miscanthus plant culture characteristics were analyzed in paper [3], for two consecutive years. The authors concluded that plant distribution after its mass, height and upper and base diameter followed a normal distribution law, the determination coefficient R^2 having high values.

Regarding plant grinding (on its two components, leaves and stalks), with a lab mill Grindomix GM-200, the authors concluded that the energy and the power of the drum necessary for grinding increases with drum revolution, values obtained being between the limits 0.594-1.080 $MJ \cdot kg^{-1}$ and 435-480 W for revolutions between 5000-9000 min^{-1}.

At the same time, in paper [4] the authors studied the mechanical behavior of miscanthus plants during uniaxial compression tests and observed the irregularity of the mechanical characteristics (tests were done on 100 plants, at various internodes), obtained from the force – deformation curves. It could be concluded that the compression force till crushing had bigger values for the lower internodes compared to the higher internodes, also a similar case happened for the elasticity module (Young module), which had the values between 55.8 MPa for the upper internodes and 128.6 MPa for the lower internodes.

In paper [5], Kronberg and his collaborators researched the mechanical behavior of reed during cutting using two methods (a blunt blade and a blade sharpened at 20º), both on one stalk and also for two or three layers of flattened stalks. They concluded that cutting only one plan does not involve many differences between the two methods but for cutting multiple layers of stalks the cutting energy increased two times between the blunt knife returned experimental values to the blade sharpened at an angle of 20º.

In our paper, a series of results are presented regarding miscanthus behavior during cutting with V shaped blades with an opening of 50º and different sharpening angles, the cutting process being done by supporting the samples in two points (cutting with shearing).

Materials and methods

From miscanthus cultures in 2010 and 2011, cultivated in the experimental field of the National Institute of Agricultural Machinery Bucharest, 100 stalks were harvested (from each year) which were subjected to a series of experimental research regarding mechanical behavior during the unaxila compression test, shearing and cutting with shearing tests and also grinding tests. The characteristics of the plants harvested in 2011 were: average base stalk diameter 8.10-12.45 mm, upper average stalk diameter 3.2-5.1 mm, 10-15 internodes, plant weight from 8.80 to 49 g, height between 125 to 285 cm. The experimental research was mode complex, the plant distribution based on the stalk height, mass and average base and top diameter was done, shearing test also, etc. For the research in this paper three similar plants were selected from 2011 harvest which had the lengths of 215, 246 respectively 255 cm, weights of 46.8, 38.4 respectively 42 g, base average diameter of 9.5, 8.3 respectively 9.02 mm, 10, 11 respectively 11 internodes. Given the fact that the plants were harvested in March, miscanthus stalks were kept in the lab in the ambient conditions (22-25 ºC, 65-67 %).

From the first seven internodes from the bottom of each plant selected, 35 samples were made, representing a total of 105 samples (3 plants x 7 internodes x 5 samples/internode = 105 samples), cut with great care with a sharp cogged knife so the outer layer of the stalks would not be affected. The samples had an average length of 30 mm, each time the average diameter (in two cross sections), sample weight being measured and also the outer later thickness (one sample for each internode after the cutting tests being made).

In order to determine the miscanthus plants behavior during cutting with shearing, V shaped blades with openings of, 30, 50 and 70º and sharpening angles (edge angles) of 10, 20, 30, 40 and 50º were made. The blades were made from a steel plate OL42, with initial hardness of 20 HRC (given by the spectrophotometer with optical emissions through sparks), they were carved, rectified and sharpened accordingly, afterwards subjected to an oil-quenching thermal treatment. Heating was done in a Nabetherm oven with electrical resistance, at an 840 ºC temperature, after which the blades were air-cooled and water-cooled, thus the blade hardness was brought to 50 HRC (because oil cooling brought blade hardness to about 44 HRC). The blade dimensions are: L = 100 mm, l = 70 mm, g = 3 mm.

In this paper only the results obtained by using blades with an opening of 50º are presented. From each internode zone one sample was used (from the five made) for testing with blades of different sharpening angles, so that the tests can be done in nearly the same testing conditions. The blade speed during the tests was of about 500 $mm \cdot min^{-1}$. The experimental tests were done by using the mechanical testing apparatus HOUNSFIELS H1KS, equipped with a force cell of 1000 N, connected to an acquisition computer data system through which we could record the cutting curves and also read the data regarding the maximum cutting force returned for each sample and also the plant deformation till definitive cutting.

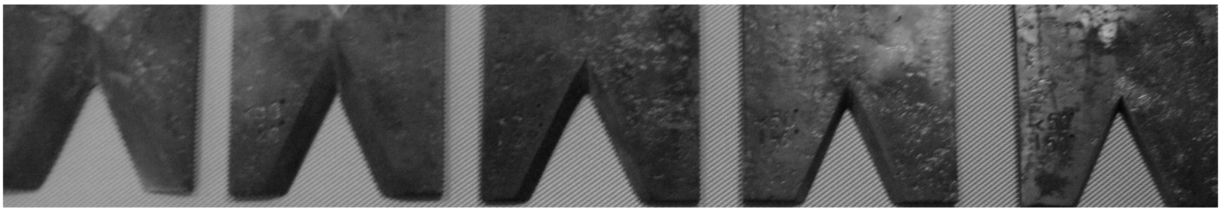

Fig. 1. **Cutting with shearing blades**

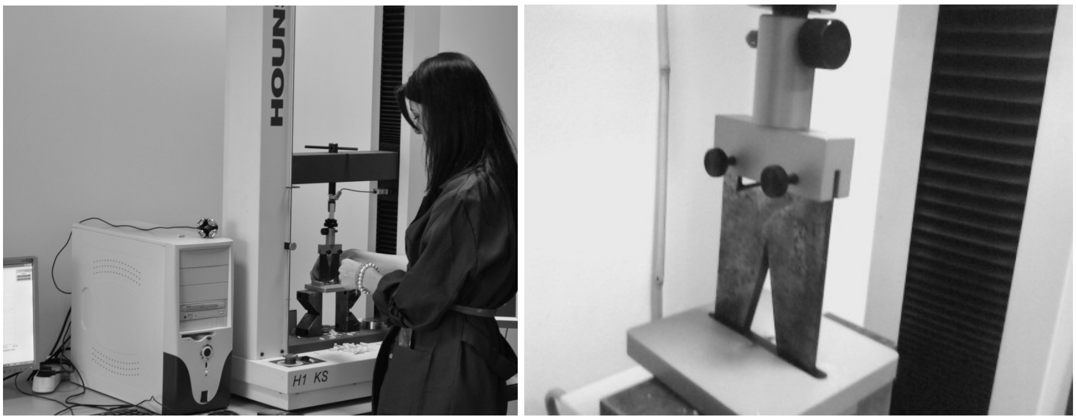

Fig. 2. **Mechanical testing machine HOUNDFIELD H1KS with a cell force of 1 KN, equipped with a plant cutting system**

Results and discussion

For every sample (from a total of 105 samples) force – extension curves were drawn, and then using the curves (through the acquisition program) data regarding the maximum cutting force, knife extension and cutting energy could be gathered.

On the curve obtained we could observe the three specific areas for cutting with shearing: stalk compression till smashing, transition zone (cutting and compression) and the area with only cutting forces.

The results for each 105 samples were then evaluated also individually for each plant as well as based on the average values of the data obtained for each internode and blade sharpening angles.

In this paper, tangential cutting tension was determined based on the proportion between the maximum value of the force given by the equipment during cutting and the area of the transversal sample section before testing (considered circular).

After the cutting test the stalk outer layer thickness was measured, also in two antipodal sections and then the average between these values was obtained. The sample characteristics for the three plants and also the cutting force values are presented in Table 1.

Based on the values in Table 1, in MsOffice Excel program, the graphics specific cutting force – average diameter and specific cutting force – stalk outer layer thickness were drawn (Fig. 3).

These graphics represent the influence of the stalk diameter on the tangential cutting tension which was calculated as the proportion between the measured cutting force and the transversal section area of the sample in the median zone on it, values being presented in MPa.

Based on the values in Table 1, the influence of the internode position on the effective cutting force was shown, for each plant and also for the average values of the tests for each three stalks. (Fig. 4).

For the experimental points shown on the graphic, computer linear regression analysis was done, using the straight line equation ($y = a \cdot x + b$). The regression equation coefficients and the determination coefficient R^2 for the graphics in Fig. 3 are presented directly on the graphics, meanwhile for the average values measured (for the three plants) and the graphics in Fig. 5 and 6 are presented in Table 2.

Table 1

Energetic parameters for the cutting process with a V shaped blade and the opening angle of 50º (for every stalk analyzed and for the average values)

Edge angle	Internode	Average diameter	Cleavage force	Tangential stress	Average diameter	Cleavage force	Tangential stress	Average diameter	Cleavage force	Tangential stress	Diameters average	Forces average	Stresses average
		mm	N	MPa	mm	N	MPa	Mm	N	MPa	mm	N	MPa
		Stalk 1			Stalk 2			Stalk 3			Average values		
10	1	9.79	636.0	8.45	8.93	314.8	5.03	9.43	488.5	7.00	9.38	479.8	6.94
	2	8.98	497.5	7.86	7.84	266.0	5.51	8.38	513.0	9.31	8.40	425.5	7.68
	3	8.95	441.5	7.02	6.85	237.0	6.43	9.15	408.5	6.22	8.32	362.3	6.67
	4	9.08	490.5	7.58	7.06	212.0	5.42	8.99	358.4	5.65	8.38	353.6	6.42
	5	8.75	379.5	6.31	7.05	228.2	5.85	8.26	315.2	5.89	8.02	307.6	6.09
	6	7.97	320.0	6.42	6.88	199.8	5.38	8.00	268.8	5.35	7.62	262.9	5.77
	7	7.44	253.6	5.84	6.66	159.6	4.58	7.54	124.5	2.79	7.21	179.2	4.39
Average		8.71	431.2	7.24	7.32	231.1	5.49	8.53	353.8	6.19	8.19	338.7	6.44
20	1	9.62	479.0	6.59	7.92	172.0	3.49	8.74	324.8	5.42	8.76	325.3	5.40
	2	8.79	363.3	5.99	7.42	197.6	4.57	7.98	277.6	5.55	8.06	279.5	5.48
	3	8.37	320.0	5.82	6.71	200.8	5.68	8.90	229.0	3.68	7.99	249.9	4.98
	4	8.76	254.4	4.22	6.00	160.8	5.69	8.27	207.5	3.86	7.68	207.6	4.49
	5	8.20	254.0	4.81	5.99	134.7	4.78	7.87	194.8	4.01	7.35	194.5	4.58
	6	7.49	204.3	4.64	5.82	114.5	4.31	7.51	182.4	4.12	6.94	167.1	4.42
	7	6.86	127.7	3.46	5.40	87.0	3.80	7.30	123.8	2.96	6.52	112.8	3.38
Average		8.3	286.1	5.29	6.47	152.5	4.64	8.08	220.0	4.29	7.62	219.5	4.82
30	1	9.58	482.0	6.69	7.90	314.4	6.42	8.78	418.0	6.91	8.75	404.8	6.73
	2	8.73	541.0	9.04	7.37	235.0	5.51	7.88	288.8	5.92	7.99	354.9	7.08
	3	7.86	354.8	7.32	7.64	183.6	4.01	8.31	289.2	5.33	7.94	275.9	5.58
	4	8.44	311.6	5.57	6.55	174.2	5.17	7.74	314.0	6.68	7.58	266.6	5.92
	5	7.84	186.0	3.85	6.53	125.6	3.75	7.61	246.8	5.43	7.33	186.1	4.42
	6	7.14	225.3	5.63	6.36	126.2	3.97	7.28	151.4	3.64	6.93	167.6	4.45
	7	6.72	185.8	5.24	5.65	116.4	4.65	6.71	169.0	4.78	6.36	157.1	4.95
Average		8.04	326.6	6.44	6.86	182.2	4.93	7.76	268.2	5.67	7.55	259.0	5.78
40	1	9.63	524.0	7.20	7.73	241.3	5.14	8.90	396.8	6.38	8.75	387.4	6.44
	2	8.87	498.0	8.06	7.66	345.6	7.50	7.79	304.0	6.38	8.11	382.5	7.42
	3	7.90	384.8	7.85	7.44	203.3	4.68	8.00	268.4	5.34	7.78	285.5	6.01
	4	7.85	294.0	6.08	6.34	185.4	5.88	7.95	239.0	4.82	7.38	239.5	5.60
	5	7.68	265.5	5.73	6.15	143.4	4.83	7.21	176.0	4.31	7.01	195.0	5.05
	6	6.83	122.3	3.34	6.09	160.4	5.51	6.93	157.4	4.18	6.62	146.7	4.27
	7	6.51	221.0	6.64	5.77	100.0	3.83	6.96	118.0	3.10	6.41	146.3	4.53
Average		7.89	329.9	6.75	6.74	197.1	5.53	7.67	237.1	5.13	7.43	254.7	5.87
50	1	9.74	805.0	10.81	7.70	327.2	7.03	8.92	500.0	8.01	8.79	544.1	8.98
	2	8.61	682.0	11.72	7.33	290.8	6.89	8.03	419.5	8.29	7.99	464.1	9.26
	3	8.12	407.0	7.86	7.21	206.5	5.06	7.51	355.2	8.02	7.61	322.9	7.10
	4	7.61	495.0	10.89	6.11	185.8	6.34	7.55	386.0	8.63	7.09	355.6	9.01
	5	7.54	334.8	7.50	6.30	173.4	5.57	7.11	257.6	6.49	6.98	255.3	6.67
	6	6.56	397.2	11.76	6.03	141.3	4.95	6.78	243.0	6.73	6.46	260.5	7.96
	7	6.45	176.4	5.40	5.70	102.1	4.00	7.30	178.4	4.26	6.48	152.3	4.62
Average		7.80	471.1	9.86	6.62	203.9	5.93	7.6	334.2	7.37	7.34	336.4	7.95

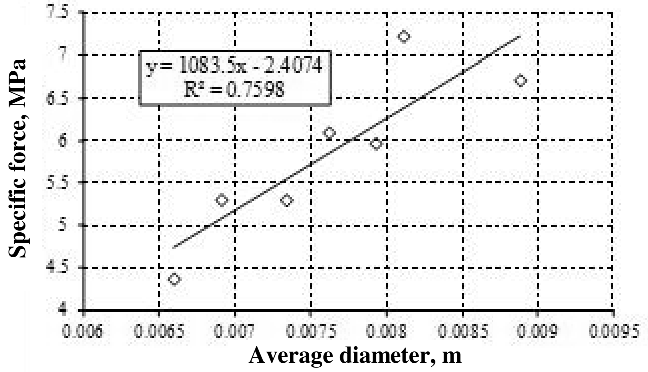

Fig. 3. **Specific cutting force in function of the average diameter values of samples**

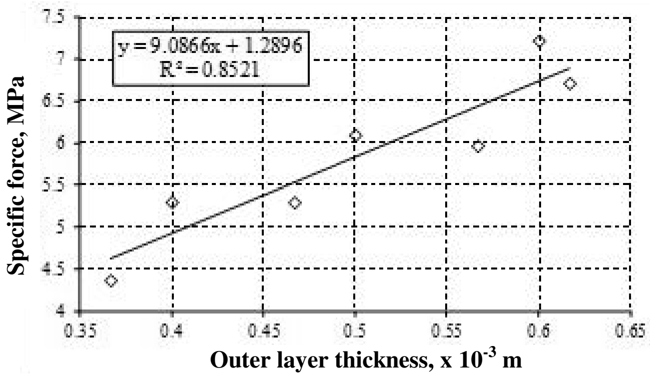

Fig. 4. **Tangential cutting tension (average values) in function of the stalk outer layer values**

Table 2

Regression equation coefficients and the determination coefficients R^2 for the average values of the cutting force in correlation with the internode position and the blade sharpening angle (average values for the three plants)

Edge angle	Determination coefficients (R^2)			Regression coefficients		
	Plant 1	Plant 2	Plant 3	*a*	*b*	R^2
10	0.905	0.893	0.928	45.77	521.79	0.971
20	0.945	0.780	0.946	32.77	350.61	0.982
30	0.8419	0.871	0.819	43.12	431.51	0.949
40	0.8746	0.688	0.965	45.90	438.31	0.950
50	0.8403	0.946	0.937	58.93	572.12	0.915

Analyzing the graphics in Fig. 3 and 4 it can be seen that the average determination coefficient R^2 has values above 0.76 which shows a good correlation between the tangential cutting tension and stalk average diameter, but especially between the tangential cutting tension and stalk outer layer thickness ($R^2 = 0.85$).

Regression equation coefficients (*a*, *b*) express experimental influence of the physical characteristics of stalks on the cutting force and also the influence of the equipment characteristics (cutting speed, plant bending in relation to the blades axis, sharpening angle, supporting stalk plate) on the cutting force and tangential tension.

Analyzing the graphic in Fig. 5 and 6 a good correlation can be seen of the experimental data (cutting force in correlation to internode position) and the regression line for each of the five blades sharpening angles with an opening of 50º. We can also say that the slope of the regression is not the same for all the sharpening angles (the lines are not parallel). Still, if we observe the data presented in Table 2, the determination coefficients R^2 are very good considered individually for every plant but mostly for the average values of the measured parameters ($R^2 > 0.915$).

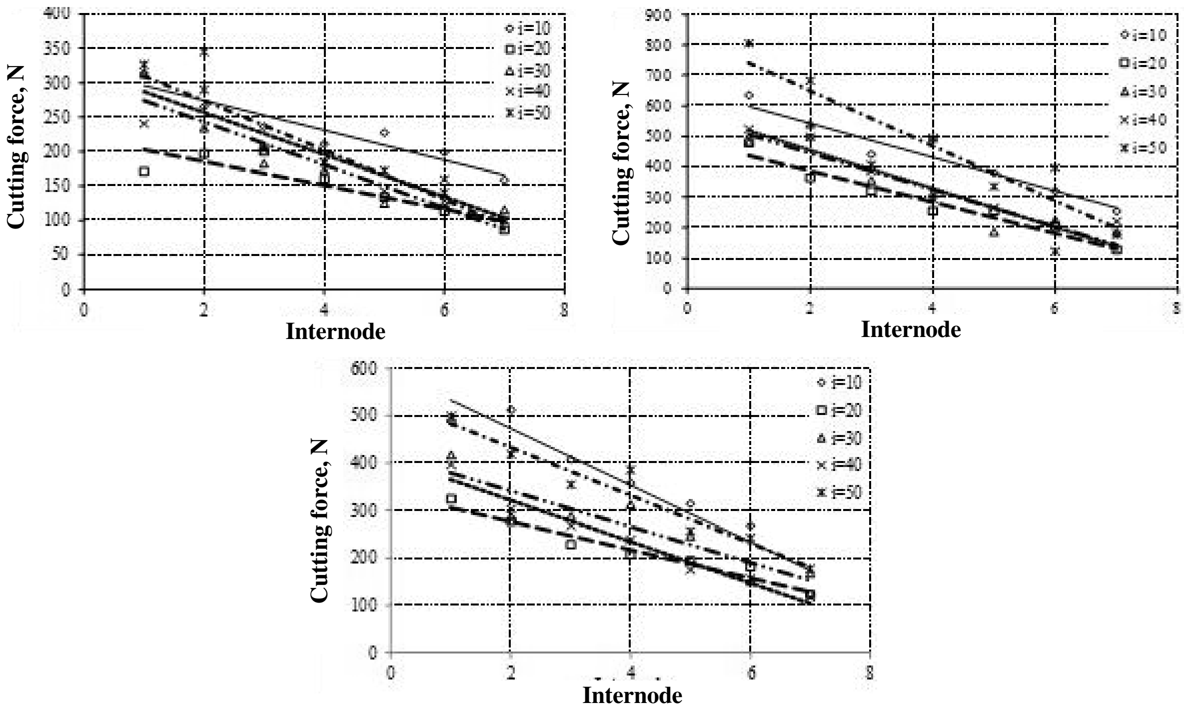

Fig. 5. **Cutting force variation in correlation with the internode position for the three plants analyzed**

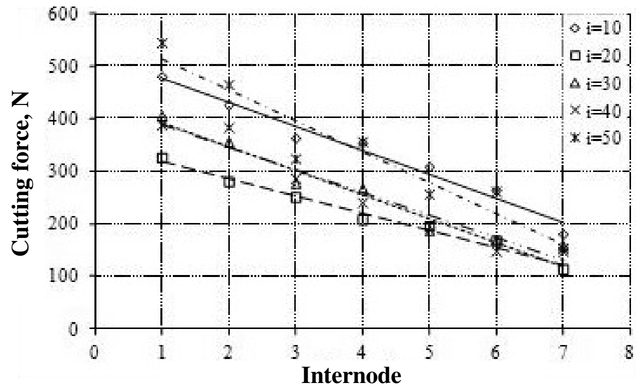

Fig. 6. **Cutting force in correlation to the internode position, considering the sharpening angle (average values)**

Conclusions

The analysis done and presented in this paper, regarding mechanical behavior of miscanthus stalks during cutting with support (cutting with shearing) using V shaped cutting blades with different sharpening angles, shows that plants are not uniform concerning the cutting force and tangential tension, according to the plants height and the internode position, but also according to the stalk diameter or stalk outer layer thickness (both in close connection to the internode position).

Nevertheless, it can be concluded that the cutting force decreases directly proportionally with the internode position (from the ground to the top of the plant) and increases directly proportionally with the stalk diameter and its outer layer thickness.

The average values of the cutting force for the V shaped blade with an opening of 50º and sharpening angles from 10º to 50º, were between the limits 273.9-585.2 N, for the base internodes and between the limits 113.0-192.9 N, for the seventh internode. Also, it could be concluded that the lowest values of the cutting force can be obtained for the sharpening angles between 25 and 30º disregarding the internode position.

The tangential cutting tension for the analyzed cases had values between 5.41-7.98 MPa, at the inferior internodes and between 3.55-5.33 MPa for the seventh internode (close distance because of the increase in plant diameter from the base to the top).

Knowing the tangential cutting tension and the cutting force can be useful in designing and obtaining adequate cutting equipment and also in selecting the optimum work parameters of the machines (shearing, cutting and grinding).

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