Durability Design of Coated Circular Saw Knife for Hot Chamber Cutting Stainless Steel in Nuclear Industry

Biwen Li [1], Jun Chen [1], Yunqiao Dong [1], Jiantao Gu [2], Hongzhe Peng [3]

[1] School of Mechanical Engineering, University of South China, Hengyang Hunan, 421001, China

[2] Nuclear Power Institute of China, Chengdu Sichuan, 610213, China

[3] Hengyang technician College, Hengyang Hunan, 421001, China

Abstract. In order to accurately investigate the changes of structure and properties of test reactor materials and components under irradiation service conditions, higher geometric accuracy and surface state requirements are put forward for the interception and cutting process of metal samples prepared by hot chamber in nuclear industry. Taking the AlCrN coated circular saw knife and the TiN thin coated circular saw knife which improve the cutting edge sharpness and the wear resistance of the substrate as the research objects, and taking the M2 circular saw knife of the same specification as the reference, the durability tests of dry cutting 316L stainless steel with two factors and two levels are carried out to verify the feasibility of the improvement of structural parameters and the long life of dry cutting at high temperature. A method of maximum durability reduction based on the variation curve of flank wear zone and hot chamber processing conditions is proposed. In this paper, a high precision tool hot chamber durability model in the form of selective subset equation is established, and the limitations of the traditional methods for obtaining the highest productivity and lowest cost durability of power function form equations are analyzed. A list calculation method for obtaining the formal durability of non-power function equations with stronger adaptability and engineering practicability is put forward, and the substitutability of the calculation results is further analyzed. The research results provide an effective method and means for the hot chamber to scientifically and reasonably formulate the tool durability to adapt to the production plan.

Keywords: Nuclear Industry Hot Chamber; Coated Circular Saw Knife; Dry Cutting Durability Model; Durability Design; List Calculation Method.

1. Introduction

The purpose of preparing and testing metal samples in the thermal chamber of the nuclear industry is to investigate the changes in the structure and properties of test reactor materials and components under service conditions. for example, the size change caused by radiation swelling, the strength reduction caused by radiation embrittlement[1,2], the grain boundary corrosion caused by fission products and so on, in order to evaluate the physical, thermal, control and operational performance of the reactor type, and improve the safety and reliability of equipment and instruments to provide accurate and reliable data. Stainless steels with good nuclear properties, room temperature and high temperature mechanical properties, chemical stability and radiation stability and easy surface cleaning are widely used as cladding[3-5], control rods and parts in contact with high temperature water. Among them, base metal, weld and welding heat affected zone supervision samples or parts must be regularly sampled for metallographic structure, accelerated intergranular corrosion, mechanical properties and other tests. Therefore, the workload of preparing stainless steel samples by hot chamber cutting is very large[6,7]. The difficulty of the work lies in: in order to avoid wet cutting waste liquid with large amount of production and complex processing process, gas cutting produces aerosols that require efficient filtration under negative pressure, the circular saw knife dry cutting process is usually used. Due to the high strengthening coefficient and work hardening ability of stainless steel, especially austenitic chromium nickel stainless steel, the tungsten high speed steel W18Cr4V (T1) circular saw knife has fast wear and low durability under dry cutting conditions, it affects the machining accuracy and the stability of the surface quality of the sample. The level of radioactivity in the hot chamber is too high, and the operator needs to control the electric or servo manipulator through the shielded observation window for long-distance processing, which is not as simple, convenient and dexterous as in the ordinary workshop environment, and the force of the manipulator is limited[8,9]. Therefore, the selection of circular saw knife with reasonable material and structural parameters and excellent dry cutting performance for the hot chamber design, and the design of scientific and reasonable tool durability and cutting parameters for the production plan has become a top priority.

2. Test of Dry Cutting Stainless Steel with Coated Circular Saw Knife and Determination of Maximum Durability of Tool Hot Chamber

2.1 Test Scheme Design

(1) Selection of tool materials: In view of the fact that the stock of T1 circular saw knife currently used in hot chamber is small, and the tungsten and molybdenum high speed steel W6Mo5Cr4V2 (M2) circular saw knife with similar hot hardness, toughness and wear resistance are easier to purchase and cheaper, therefore, the M2 circular saw knife are used as comparison knives in the test. In view of the fact that some tool coatings with excellent wet cutting performance have low thermal stability and will lose the advantage of hardness at high cutting temperature of dry sawing, they are excluded. The AlCrN coated circular saw knife with high temperature friction coefficient 0.35 and strong oxidation resistance after initial oxidation temperature over 900℃ was selected[10,11], and the TiN coated circular saw knife with high temperature friction coefficient 0.4 and better hot hardness in the range of 600 ℃ to 960 ℃ was selected as the test knife[12,13], in which the AlCrN coating was 2.5μm in normal thickness, the thickness of TiN coating was reduced to 1.5μm in order to enhance the anti-stripping property and reduce the coating cost. The coating knife substrate is made of high-performance high-speed steel with cobalt W6Mo5Cr4V2Co5 (M36), which has better hot hardness and wear resistance than M2.

(2) Optimization of tool structure parameters: The sizes of the three kinds of knives D×L×z are all 150×2×72. Leading edge rake angle and back angle of the M2 circular saw knife are 1 °and 14 °respectively, the AlCrN coating knife is changed to 2 °and 30 °, and the TiN thin coating knife is changed to 3 °and 25 °. The purpose of this is to improve the sharpness of the coating knife so as to enhance its ability to adapt to small feed cutting and heavy load cutting[14].

(3) Clamping mode and process parameters: According to the environmental conditions of the hot chamber, the circular saw knife with key cantilever installation, 25×3.5 specification 316L austenitic stainless steel pipe and knife stem wheelbase of 37.5mm, clamped with vise[15]. The thickness of the cut sample is 10 mm, and the actual path of reverse milling is calculated according to l_m= 29.057 mm. According to the industry cutting standard and the main motion speed diagram and feed speed map of X62W horizontal milling machine used in hot chamber, two-factor and two-level tests are carried out[16], that is, spindle speed n is 75, 118 r/min, x-axis feed f is 75, 118 mm/min.

(4) Division of tool wear stage and determination of blunt standard: The stages of tool wear are divided according to the evolution of chip color, the speed of tooth height reduction, vibration and screaming, and the number of machined parts during tool failure is taken as the blunt standard.

2.2 Determination of Maximum Tool Durability in Hot Chamber Environment

Table 1 shows the number of coated circular saw blades processed by four groups of cutting parameters in the test, the number of machined pieces reduced according to the environmental conditions of hot chamber and the tool durability T converted after the reduction. According to the cutting principle, the T_{max} obtained by the minimum cutting speed and feed rate(the scheme 1), is taken as the maximum tool durability under hot chamber conditions. The number of processed pieces of M2 circular saw knife in the four schemes is 241, 171, 37 and 33 respectively, which is far from the performance of the coated knife and is not intended to be used in the hot chamber. In Table 1, v is the linear speed of the knife, and f_z is the feed per tooth, which will be used for durability modeling.

Table 1. The number of machined pieces of coated circular saw knife and the hot chamber durability of the tool after reduction

	n	*f*	*v*	f_z	AlCrN Coating knife			TiN Thin coating knife		
	(r/min)	(mm/min)	(m/min)	(mm/T)	Processing	Deduction	*T*(min)	Processing	Deduction	*T*(min)
Scheme 1	75	75	35.34292	0.01389	609	465	180.153	373	347	134.437
Scheme 2	75	118	35.34292	0.02185	354	320	79.537	349	320	78.806
Scheme 3	118	75	55.60619	0.00883	299	265	102.668	187	170	65.862
Scheme 4	118	118	55.60619	0.01389	232	186	45.802	99	80	19.699

The reasons for the reduction are as follows:

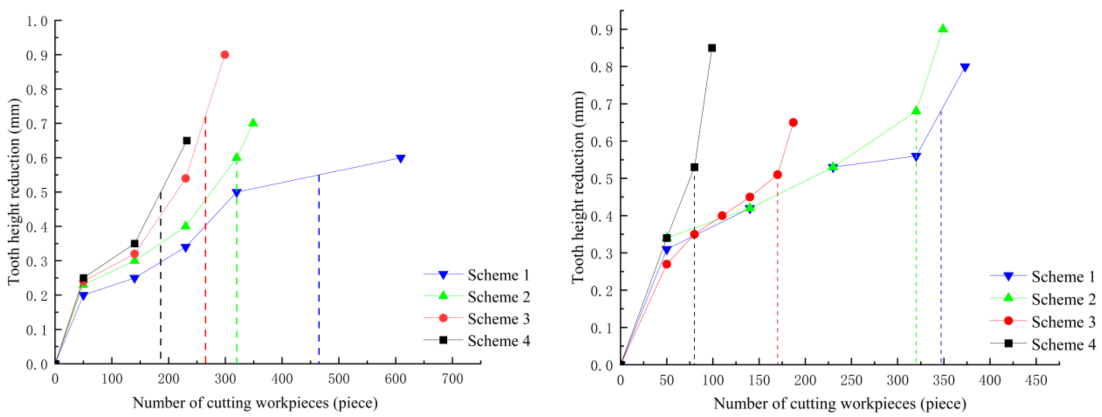
(1) The cut sample should be made to achieve the predetermined geometric accuracy. Because of the low thermal conductivity and large linear expansion coefficient of 316L stainless steel, avoid too high cutting temperature lead to thermal deformation of the workpiece and surface roughness increase[17,18], thus increase the machining allowance of the subsequent process.

(2) The influence of the cutting process on the material of the surface layer of the sample should be minimized. The sharp wear of cutting tools, the significant increase of cutting force and cutting temperature will lead to changes in hardness, grain size, chemical properties, micro cracks, residual stress and thermal damage in the surface layer of the sample[19]. However, these changes can not be completely removed in the subsequent grinding and polishing process, which is bound to affect the test results of the sample. Deduction method can make the test results more objective and credible.

(3) Based on the fact that the crossbeam and hanger are not used in the hot chamber, so that the stiffness of the machining system is low, and it is difficult to monitor the vibration phenomenon, so it is necessary to improve the blunt standard of the knife.

(4) Based on the fact that the yellow lead shielded observation window makes it difficult for the operator to observe the evolution of chip color in real time and judge the wear condition of the tool[20], it is also necessary to improve the blunt standard of the tool.

The basis for the reduction is as follows:



a AlCrN coating knife b TiN thin coating knife

Fig 1. The durability of the coating knife hot chamber reduced according to the relationship between the tooth height reduction and the number of cutting pieces

Figure 1 shows the relationship between the tooth height reduction of the coated circular saw knife and the number of cutting pieces measured by sampling. when the flank wear band width increases to a certain limit, serious boundary wear will occur, causing the knife to slip and lose the cutting ability[21]. Based on the reduction method, the curve of the later wear stage is cut in half by the curve with relatively gentle or large span, and the curve segment with steeper or smaller span is cut out, as shown by the dotted line in the figure. This should be able to achieve a balance between processing quality, observation and control workload and economic benefits to a great extent. The mechanism of the characteristics of the curve in figure 1 has been described in another article, which will not be repeated in this paper.

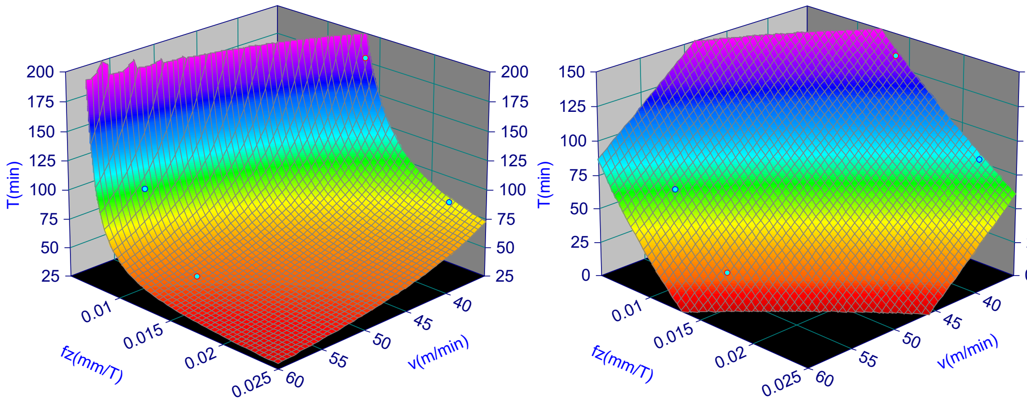
2.3 Knife Hot Chamber Durability Model based on TableCurve 3D

Based on the three-dimensional curve fitting software TableCurve 3D, the durability mold of coated circular saw knife dry sawing 316L stainless steel with ideal continuity, smoothness and shape retention[22,23], correlation index $R^2 \geq 0.9999$ and residual standard error $\sigma \leq 0.655$ was established. The expressions of the durability model of AlCrN coating knife and TiN thin coating knife are as follows:

$$T = 1/(a + bv + c\ln f_z / f_z) = 1/(-6.485616\times10^{-3} + 8.013993\times10^{-4} v + 5.290096\times10^{-5} \ln f_z / f_z) \tag{1}$$

$$T = a + bv + c/\ln f_z = 8.091651\times10^{2} - 5.658917v + 2.028961\times10^{3}/\ln f_z \tag{2}$$

Although the expressions of formulas (1) and (2) are different, they both belong to the form of selective subset equation[24,25]. Figure 2 shows the three-dimensional graph of the model. Compared with the traditional method of establishing the durability model of nonlinear power function form $T = C_T/v^{1/m} f_z^{1/m}$ based on the linear equation relationship of $vT^m = C_0$ and $f_z T^{m1} = C_1$, the modeling based on TableCurve 3D has the advantages of less sample points require, high model accuracy, low test cost and quick modeling.



a AlCrN coating knife b TiN thin coating knife

Fig 2. 3D diagram of durability model for hot chamber dry sawing 316L stainless steel with two kinds of circular saw knife

3. Design of Maximum Productivity Durability of Hot Chamber Coated Circular Saw Knife

3.1 The Durability of Maximum Productivity and the Limitations of Traditional Calculation Methods

The tool hot chamber durability model is based on the experimental data, strictly speaking, it is not based on the mathematical relationship between durability and cutting amount derived from physical nature, but it is an empirical formula with engineering practicability. From the point of view of ensuring machining accuracy and surface quality, reducing tool consumption and tool replacement workload, and reducing the amount of decontamination disposal of waste tools, it is reasonable to adopt the highest durability. However, it is difficult to quantitatively evaluate its impact on productivity and processing costs.

In the case of urgent scientific research and production tasks, the durable cutting conditions with the highest productivity will be preferred. The durability of the highest yield T_P is the durability of the maximum number of products per unit time, and the corresponding single-piece process man-hour t_w is the smallest.

The t_w formula for calculating the working hours of a single process is[15]:

$$t_w = t_m + t_{ct}\frac{t_m}{T} + t_{ot} \tag{3}$$

In the formula:

t_m—Cutting time of process, time-consuming calculation according to the actual distance of cutting through the workpiece l_m , that is: $t_m= l_mD\pi / 1000zvf_z$;

t_{ct}—The time it takes to change the knife in the hot chamber at once. Due to the installation of circular saw knife with key, it is inconvenient for teleoperation manipulator to grasp, shift and rotate angle alignment, so it is taken as 14.5min according to practical experience;

t_m/T—Number of knife changes;

t_{ot}—Excluding the auxiliary working hours of tool changing time, including tool return, installation and adjustment of workpieces, cleaning chips and so on, so it is taken as 2.5 min according to practical experience.

The traditional method for calculating the durability of the highest productivity[26]: first select the f_z value corresponding to the larger f value, which is based on the fact that the effect of feed f on durability T is smaller than that of cutting speed v, and the higher the f value, the higher the productivity. The relation of $v = C_0/T^m$ is substituted into the formula $t_m= l_mD\pi /1000zvf_z$ and processed into the form of $t_m=AT^m$. After substituting the formula into formula (3), the calculation formula of form $t_w=AT^m+t_{ct}AT^{m-1}+t_{ot}$ is obtained. The T value obtained by solving $dt_w/dT= 0$ is taken as the highest productivity durability T_P, and the corresponding cutting speed v_P can be obtained according to the v-T relation.

The limitations of traditional methods are as follows:

(1) The higher the f value, the greater the cutting force, this will inevitably further aggravate the original flaking resistance due to the coating, the increase in sharpness reduces the heavy duty cutting burden of the coating tool with anti-breakage properties, and affects the applicability of coated tools.

(2) The higher the value of f, the greater the cutting resistance, it is worth discussing whether it matches the reduced system stiffness due to the non-use of crossbeams and hangers. The higher the f value is, the worse the surface roughness of the sample is, and the worse it will be in the later wear stage of the tool, so the stability of the surface quality is not optimistic.

(3) The lower the v value, the higher the durability T, but in the lower cutting speed region, the Built-up edge may increase the knife durability because of stability, or decrease the knife durability due to instability leading to the collapse of the knife[27,28]. The applicable scope of the equation $v = C_0/T^m$ is limited because of the non-single linear relationship of v-T in the lower cutting speed region.

(4) The v_P value obtained according to the continuous function needs to be rounded to the nearest discrete value corresponding to the machine tool speed n, and the f_z value obtained from the relation of $f_z = f D \pi /1000zv$ limits the rounding of v_P greatly[29].

3.2 Maximum Productivity Durability List Calculation Method for Non-Power Function Equations

According to formulas (3) and (1), the formula for calculating the working hours of single piece of AlCrN coated knife is obtained as follows:

$$t_w = \frac{1.5241012(T+14.5)}{f_zT(1/T + 6.4856155\times10^{-3} - 5.290096\times10^{-5}\ln f_z/f_z)} + 2.5 \tag{4}$$

According to formulas (3) and (2), the formula for calculating the working hours of a single piece of TiN thin coating knife is obtained as follows:

$$t_w = \frac{-1.0762129(T+14.5)}{f_zT(T - 8.0916514\times10^{2} - 2.0289605\times10^{3}/\ln f_z)} + 2.5 \tag{5}$$

The formula t_w=AT_m+t_{ct}AT^{m-1}+t_{ot} of the traditional method is a power function equation, but for the formulas (4) and (5) evolved from the selective subset equation, the equation does not necessarily have a solution when dt_w/dT= 0. In order to obtain t_{wmin} and avoid rounding of v_P values, this paper proposes a design and calculation method of maximum productivity durability, which first lists table, then calculates t_w based on MATLAB programming, and finally matches T_P and v_P values based on TableCurve 3D built-in interpolation function. Considering that the rotation speed of X62W is 95 r/min and the feed rate of 95 mm/min is within the range of test process parameters, the XA6132 horizontal milling machine to be added in the hot chamber has only 80 mm/min and 100 mm/min feed rates in the test range (the main motion rotational speed diagram of this type is the same as that of X62W). In order to expand the practicability of the design results of durability, all the cutting parameters of the two types of machine tools in the range of test values are combined, 11 new groups of schemes have been added. The calculated t_w values, matched T values and v values of 15 groups of schemes are listed in Table 2. After comparison, the T_P value of the highest productivity and durability and its matching cutting parameters v_P and f_z can be directly obtained. In order to facilitate the comparison, table 2 combines the same schemes in f, sorted incrementally by f and n.

Table 2. Working hours of a single process and corresponding durability of 15 cutting schemes for hot chamber of coated circular saw knife

	n	f	v	f_z	AlCrN Coating knife		TiN Thin coating knife	
	(r/min)	(mm/min)	(m/min)	(mm/T)	T(min)	t_w(min)	T(min)	t_w(min)
Scheme 1	75	75	35.34292	0.01389	180.163	2.91858	134.728	2.92909
Scheme 6	95	75	44.76770	0.01096	131.480	2.93035	106.297	2.94048
Scheme 3	118	75	55.60619	0.00883	102.650	2.94204	65.502	2.97307
Scheme10	75	80	35.34292	0.01481	147.245	2.89911	127.505	2.90465
Scheme11	95	80	44.76770	0.01170	107.770	2.91194	99.694	2.91590
Scheme12	118	80	55.60619	0.00942	84.176	2.92561	59.554	2.95147
Scheme 5	75	95	35.34292	0.01759	103.233	2.84888	106.997	2.84737
Scheme 7	95	95	44.76770	0.01389	76.315	2.86395	81.394	2.86033
Scheme 9	118	95	55.60619	0.01118	59.473	2.88050	42.975	2.90913
Scheme13	75	100	35.34292	0.01852	95.747	2.83455	100.511	2.83247
Scheme14	95	100	44.76770	0.01462	70.911	2.84999	75.643	2.84627
Scheme15	118	100	55.60619	0.01177	55.214	2.86689	37.748	2.90220
Scheme 2	75	118	35.34292	0.02185	79.485	2.79120	78.515	2.79175
Scheme 8	95	118	44.76770	0.01725	59.030	2.80676	56.077	2.80995
Scheme 4	118	118	55.60619	0.01389	45.894	2.82402	20.060	2.92421

As can be seen from table 2:

(1) For AlCrN coating tools, the general trend of t_w value distribution is: when n is the same, the larger f is, the smaller the t_w value is. When f is the same, the smaller n is, the smaller the t_w value is. Therefore, scheme 2 with maximum f and minimum n gets t_{wmin}, corresponding to the highest productivity durability T_P = 79.485min. The results are different from the corresponding T_{max} = 180.163min of scheme 1, so it can be seen that the influence of tool changing time plays a decisive role.

(2) For TiN thin coating tools, the general trend of t_w value distribution is as follows: except for the scheme with n = 118 r/min, the law exists that the larger f is, the smaller the t_w value is when n is the same. The analysis should be that the tool durability of high speed dry cutting under large feed is seriously reduced, resulting in the excessive proportion of tool replacement time in the t_w value. When f is the same, the smaller the n is, the smaller the t_w value is; the T_P in scheme 2 is different from the T_{max} corresponding to scheme 1.

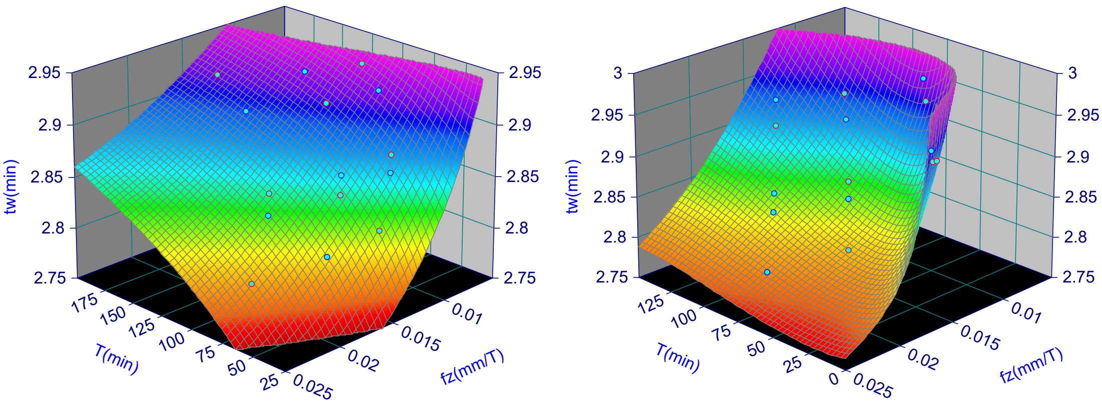
(3) The law that the larger the f is, the smaller the t_w value is, which reflects that in most cases, the process cutting time t_m plays a decisive role in the t_w value.

(4) For scheme 2, the t_{wmin} value and T_P value of AlCrN coated knife are only slightly better than that of TiN thin coated knife.

3.3 Analysis of the Advantages of List Calculation Method

The advantages of list calculation method are reflected in the convenience of t_w solution, the visualization of result comparison and the richness and applicability of data.

(1) It is convenient to solve the equation whose t_w formula is a non-power function. Figures 3a and 3b are three-dimensional diagrams of formulas (4) and (5) respectively. It can be seen that even if the value of f_z is given first, t_{wmin} is still unsolvable in the case of $dt_w/dT = 0$. It should be noted that when establishing the durability model, it should also consider that it can be reduced to a laconic v-T relationship expression.



a AlCrN coating knife b TiN thin coating knife

Fig 3. The relationship between t_w, T and f_z of two kinds of circular saw knives

(2) v_P values do not need to be round, and the law of data distribution is clear at a glance.

(3) It facilitates the analysis and comparison of the data. For X62W horizontal milling machine, when using AlCrN coating knife, compare scheme 1 to scheme 9 in the list, it can be found that scheme 5 has a comprehensive advantage over scheme 2, when its t_w value only increases by 2.07% (0.05768min), the T value is significantly increased by 29.88% (23.748min), which translates to 17 more pieces than that of scheme 2. What is important is that the f and f_z values have significantly decreased by 19.49% compared with the same period, which should be able to achieve obvious results in reducing the cutting burden of knife teeth, reducing the stiffness requirements of the system, and improving the stability of surface quality, therefore, scheme 5 can be considered as an alternative to scheme 2. The same consideration can be made when using TiN thin coating knife. For XA6132 horizontal milling machine, compared with the scheme 10 to 15 in the list, scheme 13 has obvious comprehensive advantages, and the feed rate is more appropriate at this time, therefore the alternative can be ignored.

4. Design of Minimum Cost Durability of Hot Chamber Coated Circular Saw Knife

4.1 Comprehensiveness and Calculation Formula of Minimum Cost Durability

On the premise of making full use of the technical performance of horizontal milling machine and the cutting performance of coated circular saw knife, the maximum tool durability and maximum productivity durability can be designed to meet different needs[30], but these two kinds of durability do not mean that the processing cost is effectively controlled. Due to the high unit price of the coated circular saw knife and the high labor cost of the hot chamber in the nuclear industry, the increase in cutting time may lead to the increase of processing cost when the durability is very high, and the increase of tool consumption and tool changing time may lead to the increase of processing cost when the durability is very low. The lowest cost durability of machine tool cost, manipulator cost, tool cost and labor cost is comprehensively considered in normal production, it is formulated on the principle of the lowest processing cost of per product.

The C formula for calculating the cost of a process of a single product as:

$$C = t_{\mathrm{m}}M + t_{\mathrm{ct}}\frac{t_{\mathrm{m}}}{T}M + \frac{t_{\mathrm{m}}}{T}C_{\mathrm{t}} + t_{\mathrm{ot}}M \tag{6}$$

In the formula:

M—The cost of the whole plant shared by the hot chamber sample cutting process per unit time, including the cost of decontamination;

C_t—Cost of disposable coated tools for hot chamber.

According to the calculation of the enterprise, M is set at 15.78 yuan, the unit prices of AlCrN coating knife and TiN thin coating knife are 150 yuan and 75 yuan respectively.

4.2 Calculation Results and Analysis

When using AlCrN coating tool, the process cost C of a single product is:

$$C = \frac{2.405032\times10^{-3}T + 5.773448\times10^{-2}}{f_{\mathrm{z}}T(1/T + 6.485616\times10^{-3} - 5.290096\times10^{-5}\ln f_{\mathrm{z}}/f_{\mathrm{z}})} + 39.45$$

When using TiN thin coating knife, the process cost C of a single product is:

$$C = \frac{-16.982639T - 2.618533\times10^{2}}{f_{\mathrm{z}}T(T - 8.091651\times10^{2} - 2.028961\times10^{3}/\ln f_{\mathrm{z}})} + 39.45$$

In order to avoid the limitations of the traditional solution method, the list calculation method is also used, and the results are shown in table 3.

Table 3. Single-piece process cost and corresponding durability of 15 cutting schemes for hot chamber of coated circular saw knife

	n	f	v	f_z	AlCrN Coating knife		TiN Thin coating knife	
	(r/min)	(mm/min)	(m/min)	(mm/T)	T(min)	C(yuan)	T(min)	C(yuan)
Scheme 1	75	75	35.34292	0.01389	180.163	46.378	134.728	46.436
Scheme 6	95	75	44.76770	0.01096	131.480	46.683	106.297	46.674
Scheme 3	118	75	55.60619	0.00883	102.650	46.991	65.502	47.358
Scheme10	75	80	35.34292	0.01481	147.245	46.118	127.505	46.048
Scheme11	95	80	44.76770	0.01170	107.770	46.456	99.694	46.285
Scheme12	118	80	55.60619	0.00942	84.176	46.813	59.554	47.031
Scheme 5	75	95	35.34292	0.01759	103.233	45.400	106.997	45.145
Scheme 7	95	95	44.76770	0.01389	76.315	45.794	81.394	45.417
Scheme 9	118	95	55.60619	0.01118	59.473	46.226	42.975	46.439
Scheme13	75	100	35.34292	0.01852	95.747	45.184	100.511	44.912
Scheme14	95	100	44.76770	0.01462	70.911	45.587	75.643	45.202
Scheme15	118	100	55.60619	0.01177	55.214	46.029	37.748	46.374
Scheme 2	75	118	35.34292	0.02185	79.485	44.510	78.515	44.288
Scheme 8	95	118	44.76770	0.01725	59.030	44.917	56.077	44.670
Scheme 4	118	118	55.60619	0.01389	45.894	45.368	20.060	47.064

By analyzing Table 3, we can find that:

(1) Except for the disturbance caused by the sharp decrease of T value in scheme 4 of TiN thin coating knife, the two types of coating knives basically show the rule that in regions where the f value is larger, the C value is smaller, indicating that the decrease of t_m value which is directly affected by f value affects the calculated value of C.

(2) The C_{min} values of the two kinds of coated knives are both in scheme 2. When the number of machined pieces is equal, the processing cost per piece of using TiN thin coated knives is reduced by 0.222 yuan, which is contrary to the advantage of t_{wmin} value, and the effect of tool unit price is reflected.

(3) For X62W horizontal milling machine, when using AlCrN coating knife, the scheme closest to the *C* value of scheme 2 is scheme 8. The decrease of f_z value of this scheme by 21.05% should play a certain role in improving the stability of surface quality, however, the *C* value has significantly increased by 0.407 yuan, and the number of processed pieces has been significantly reduced by 82 pieces, which makes it difficult to replace scheme 2. For TiN thin coating knife, the comprehensive advantage of scheme 2 is also particularly obvious. For XA6132 horizontal milling machine, scheme 13 shows obvious comprehensive advantages compared with the scheme 10 to 15 in the list.

(4) Analyze the economic feasibility of scheme 5 replacing scheme 2, the processing costs of the two kinds of coated knives have been greatly increased by 0.89 yuan and 0.857 yuan respectively. This may apply in the pursuit of maximum productivity, but it remains to be discussed for long-term normal production.

5. Conclusion

The design of the durability of the hot chamber cutting circular saw knife should be based on meeting the geometric accuracy and surface state requirements of the sample, and at the same time corresponding to the processing efficiency and economic benefits of the production plan. The structural parameters of two kinds of coated circular saw knives and the test results of dry cutting performance of stainless steel provided in this paper can be used as a reference for choosing coating knife materials and improving tool structure parameters in hot chamber. The proposed maximum durability reduction method can effectively avoid the serious deterioration of the geometric accuracy of the sample and the serious change of the surface layer material. The proposed durability modeling method has the advantages of small test quantity and high precision. The list calculation method of maximum productivity durability and minimum cost durability in the form of non-power function equation and its result substitution scheme have certain advantages, universality and practicability. It can be used as a method to design and decide the tool durability for different production plans by combining the technical and economic characteristics of the hot chamber.

References

[1] Su, M., Li, Y., Chen, p., Wang, H., Pu, Z., Qi, m., & Zhu, F. (2017). Preliminary numerical simulation of fuel assembly deformation under non-uniform irradiation environment. Nuclear power engineering(S2),7-10.doi:10.13832/j.jnpe.2017.S2.0007.

[2] Gong, X., Ding, S., Zhao, Y., Huo, Y., Zhang, L., & Li, Y. (2013). Effects of irradiation hardening and creep on the thermo-mechanical behaviors in inert matrix fuel elements. Mechanics of Materials, 65, 110-123.

[3] Chen, D., Liu, X., He, Q., Xu, Y., & Liu, H. (2021). Study on performance optimization of austenitic heat-resistant stainless steel 22Cr21Ni12 for nuclear industry. Functional materials(11), 11215-11220.

[4] Ucak, N., Aslantas, K., & Cicek, A. (2020). The effects of Al2O3 coating on serrated chip geometry and adiabatic shear banding in orthogonal cutting of AISI 316L stainless steel. Journal of Materials Research and Technology, 9(5), 10758-10767.

[5] Struzikiewicz, G., Zębala, W., Matras, A., Machno, M., Ślusarczyk, Ł., Hichert, S., & Laufer, F. (2019). Turning research of additive laser molten stainless steel 316L obtained by 3D printing. Materials, 12(1), 182.

[6] Zhu, Q., Wang, M., Sun, Y., Zhang, L., Qin, H., & Zhang, P. (2023). Effects of Ultra-Low Temperatures on the Mechanical Properties and Microstructure Evolution of a Ni-Co-Based Superalloy Thin Sheet during Micro-Tensile Deformation. Materials, 16(21), 6838.

[7] Lian Peisheng, & Luo Qi. (2024). Atomic energy industry. BeiJing: China Atomic Energy Publishing House.

[8] Liang, R., Peng, S., Wang, G., & Wu, D. (2021). Exploration of new hot cell scheme design. Industry and Technology Forum(01),47-48.

[9] Dong, M. (2023). Research on auxiliary observation system of power manipulator in nuclear industry(Master thesis, Nanjing University of Science and Technology). https://link. cnki. net/doi/ 10. 272 41/d. cnki. gnjgu.2023.001339doi:10.27241.

[10] Michalak, M., Michalczewski, R., Osuch-Słomka, E., Maldonado-Cortés, D., & Szczerek, M. (2016). The effect of temperature on wear mechanism of the AlCrN coated components. Key Engineering Materials, 674, 233-238.

[11] Cai, Z., Di, Y., & Zhang, p. (2010). Microstructure and high temperature oxidation resistance of CrAlN coating on piston ring surface. China Surface Engineering(06),15-19.

[12] Zemzemi, F., Rech, J., Ben Salem, W., Dogui, A., & Kapsa, P. (2007). Development of a friction model for the tool-chip-workpiece interfaces during dry machining of AISI4142 steel with TiN coated carbide cutting tools. International Journal of Machining and Machinability of Materials, 2(3-4), 361-377.

[13] Xu, J., Wang, G., Wang, J., Wang, C., Yin, Z., Wang, Y., & Chen J. (2020). High temperature oxidation characteristics of TiN coating by multi-arc ion plating. welding technique (11), 14-16.doi: 10. 13846/ j. cnki.cn12-1070/tg.2020.11.004.

[14] Jin, Y., & Qi, w. (2021). The influence of tool structure on the quality of mechanical cutting and optimization ideas. Agricultural machinery uses and maintenance (02), 43-44.doi: 10.14031/j. cnki. njwx. 2021. 02.019.

[15] Chen Ri yao. (2002). Theory of metal cutting. BeiJing: Mechanical Industry Press.

[16] East China Textile Institute, Harbin Institute of Technology, Tianjin University. (1984). Machine tool design atlas. Shanghai: ShangHai Science and Technology Press.

[17] Wang, T.,& Yi, M. (2023). Effect of nano hBN on dry cutting of 316 stainless steel with cemented carbide tools. Tools technology(11),35-39.

[18] Ozcelik, B., Kuram, E., & Simsek, B. T. (2011). Comparison of dry and wet end milling of AISI 316 stainless steel. Materials and Manufacturing Processes, 26(8), 1041-1049.

[19] Jia, S., Han, J., Liu, Y., Shi, W., Yang, Y., & Ma, T. (2023). Comparative study on cutting performance of different micro-texturing milling tools for preparing the L-PBF-formed TC4 workpieces. Journal of Manufacturing Processes, 108, 596-609.

[20] Duan, H. (2010). Technical characteristics of hot room peep window. (eds.) Proceedings of the 30 ~ (th) Anniversary Celebration Conference of Nuclear and Chemical Industry Branch of China Nuclear Association & Annual Conference of National Nuclear and Chemical Engineering Academic Exchange (pp.155-158). China Nuclear Power Engineering Co., Ltd.

[21] Lu Bingheng. (2008). Mechanism manufacture technology basis. BeiJing: Mechanical Industry Press.

[22] Zhou, Y. (2020). Design of visual process control system for double-sided submerged arc welding of thick-walled components with gap(master degree thesis, University of South China). https://link. cnki. net/ doi/10.27234/d.cnki. gnhuu. 2020.001267 doi:10.27234.

[23] Fu, N., & Chen, Y. (2016). Discussion on GPS Height Fitting Based on TableCurve 3D. Jiangxi Surveying (01), 25-26.

[24] Vo, A. D., Elraghy, A., & McAuley, K. B. (2018). Parameter Subset Selection in Differential Equation Models with Dead Time. IFAC-PapersOnLine, 51(18), 661-666.

[25] Riahi-Madvar, H., Gholami, M., Gharabaghi, B., & Seyedian, S. M. (2021). A predictive equation for residual strength using a hybrid of subset selection of maximum dissimilarity method with Pareto optimal multi-gene genetic programming. Geoscience Frontiers, 12(5), 101222.

[26] Ren Jialong, liu Zhi feng, & Tang wengxian. (2012). Dry cutting theory and processing technology. Beijing: Mechanical Industry Press.

[27] Fan, S., Fan, Y., Xu, X., & Wang, J. (2023). Cutting force and tool wear test of titanium alloy Ti750. Journal of Jiangsu University (Natural Science Edition)(04),426-430+436.

[28] Cai, Q., Sheng, G., She, G., Wang, H., & Chen, J. (2020). The influence of turning hardening and cutting speed on tool life of nuclear grade 316L stainless steel is studied. Tools technology(09), 29-32.

[29] Bai Qingshun, Sun Jingmin, & Liang Yingchun. (2017). Mechanical Optimization Design (6th Edition). Beijing: Mechanical Industry Press.

[30] Jing, C., Zheng, G., Cheng, X., Cui, Y., Liu, H., & Zhang, H. (2024). Cutting performance and machining economy of the hard cutting tools in clean cutting of hardened H13 steel. The International Journal of Advanced Manufacturing Technology, 130(11), 5165-5179.