DOI: 10.21062/mft.2022.022 http://www.journalmt.com

Study on Lapping Process of 304 Stainless Steel Using Tribochemical Fixed-Abrasive Lapping Platen

Jianxiu Su (0000-0001-7366-501X), Xiaofeng Zhang (0000-0002-8996-0512), Mingpu Xue (0000-0002-4030-2949), Wen Xiao (0000-0002-7541-4000), Tianyi Zhang (0000-0002-1474-2019)
Henan Institute of Science and Technology, Xinxiang, 453003, China. E-mail: dlutsu2004@yeah.net

Based on the previous research on the 304 stainless steel lapping and polishing in our research group, the tribochemical fixed-abrasive lapping platen for 304 stainless steel lapping and polishing were developed. The effects of the different pressure, the rotation speed, the lapping time and the abrasive size on the surface roughness and the material removal rate (MRR) were researched. It was concluded that when the abrasive size is 28 μm, the lapping time is 15 min, the lapping speed is 90r/min, the lapping pressure is 27.580 KPa, and the maximum MRR is 412.524 nm/min. When the lapping time is 15 minutes, the rotating speed is 15 r/min, the lapping pressure is 13.790 KPa, the surface roughness *Ra* drops to 41nm. These findings show that the influence degree on the MRR from better to worse is the abrasive size, the lapping pressure, the rotation speed of the lapping platen and the lapping time. The order of the influence degree on the surface roughness from better to worse is the abrasive size, the rotation speed of the lapping platen, the lapping pressure and the lapping time. The results can give an important reference for next study on the tribochemical mechanical lapping of fixed-abrasive.

Keywords: Material removal rate, Surface roughness, Fixed-abrasive lapping, Tribochemistry, 304 stainless steel.

1 Introduction

With the rapid development of science and technology, flexible display products has become a research hotspot due to its ultra-thin, flexibility, retract ability and light weight [1-2]. Because of these excellent characteristics, it has a wide range of applications in civil field, industry field and military field [3-5].

Among these flexible display devices, select and preparation of the flexible substrate are the key of the research and development of flexible display products [6-7]. As flexible substrates, they have to have these properties, such as the ultra-thin, the high flexibility and the toughness. In addition, the flexible substrate should have high thermal stability, good chemical corrosion resistance, suitable thermal expansion coefficient and light weight [8]. All of which will directly affect the production of devices and product quality [9-10]. At present, the flexible display substrate mainly includes ultra-thin glass, polymer substrate, metal substrate and grapheme [11-12].

Among these substrates, the ultra-thin stainless steel substrate has these superior properties abovementioned, for instance the low electrostatic effect, the light weight, the curling, the strong corrosion resistance, and its coefficient of thermal expansion is close to that of glass. Because the stainless steel substrate has the good water and oxygen resistance performance, it does not need the preparation of water oxygen barrier layer. In addition, the high temperature resistance of stainless steel substrate (at least above 1000℃) is much higher than that of plastic and glass. There will be no heat resistance problem when using stainless steel substrate in the manufacturing of flexible display [13-14]. The stainless steel substrate is also suitable for the roll to roll production process, and can be directly compatible with the current semiconductor production process. So, it is easy to manufacture for TFT devices, and so on. For these reasons, the stainless steel material has these properties, such as the physical, chemical and mechanical performance and low cost, needed for the flexible display abovementioned, and therefore which may become an ideal material for the next generation of flexible display substrate [6-8, 11-12]. Therefore, stainless steel material is very suitable for the flexible substrate material in flexible display products, which has been widely used in flexible display at present [15-16].

In a word, the stainless steel material has become the one of the flexible substrate in the manufacturing of the flexible display product in the future due to its good performance and low cost. On December 6, 2019, China Association of special steel enterprises issued the group standard about ultra-thin stainless steel precision strip for flexible display screen, the standard No. is T/SSEA 0039-2019, which will be implemented from now on [17].

The performance of devices will be affected by the surface processing quality and accuracy [18-20]. For flexible display substrates, the surface accuracy requirements are very high, such as the waviness should be less than 0.1 μm and the surface roughness should be less than 5 nm. However, the surface roughness of the commercially available stainless steel sheet is so large that it can't meet their requirements of flexible display substrates on surface quality. So, it can't be used as a flexible substrate directly, otherwise it will affect the performance of flexible display. So, before used, the stainless steel sheet must be ultra precision machined [21].

The lapping is one of the main method in ultra-precision machining for the stainless steel substrate. In the lapping process, it is primarily to reduce or remove surface scratches, reduce the surface roughness, decrease the subsurface damage and improve the flatten of the substrate. So, in following chemical mechanical polishing (CMP) process, the surface quality of the stainless steel substrate after lapped has much influence on the CMP time, the CMP efficiency, the CMP quality and CMP cost. Therefore, the theory, process and technology of ultra-precision lapping for the stainless steel substrate must be studied with high efficiency, high quality and low cost, this will be of great practical significance.

Literatures show that, in the ultra-precision machining of the stainless steel substrate, some researchers have been conducted in-depth study using these machining method, such as grinding, free abrasive lapping and fixed abrasive lapping [22-24] and have gained some abundant research achievements. Under the support of NSFC, our research group have deeply studied the ultra-precision machining of the stainless steel substrates in recent years [25-28]. However, in lapping the stainless steel substrate, some key problems, such as the serious surface and subsurface damage, low lapping efficiency and so on, have not been solved, this will restrict the large-scale production and application. At present, the most urgent problem to be solved is to try to improve the machining efficiency and reduce and eliminate the surface damage in the lapping of the stainless steel substrate.

Tribochemistry is an interplateniplinary subject of chemistry and tribology. It mainly is concerning these studies in the chemical and physicochemical changes of solid surfaces in relative motion under the influence of mechanical energy. The use of mechanical energy to stimulate chemical reactions is one of the oldest experiments in human history. Man has used flint to make fire [29-30]. The tribochemical reaction between two friction surfaces may be caused by friction temperature, catalysis in friction surfaces and mechanical energy. All kinds of physical and chemical effects is directly related to each other relative motion of friction surfaces, and the surface lattice defects and new metal surfaces caused by wear also have catalytic effects on chemical reactions [31-32]. According to literatures, it is found that, in the ultra-precision machining hard and brittle materials, the tribochemical action can cause chemical reaction on friction surface, which can further improve the material removal rate (MRR) and reduce the production cost [33-34]. But now there are no literatures to show the tribochemical mechanical lapping of the stainless steel substrates. Therefore, inspired by this method, took the 304 stainless steel as research object, the method of the tribochemical mechanical lapping has been proposed by our research team to machining the stainless steel substrates.

Research results showed that there are some disadvantages in free abrasive lapping, such as low machining efficiency, serious surface damage, low abrasive utilization ratio and high machining cost [35-36]. So, in this paper, the fixed-abrasive lapping platens with tribochemical reaction were developed, the lapping process with these platens was studied and the most reasonable optimum technological parameters was found. The experimental results were analyzed and some useful conclusions were obtained. In the next step, our research team will focus on these researches of the material removal mechanism and surface morphology and formation on the tribochemical mechanical lapping of the stainless steel substrate.

2 Experimental conditions and methods

Four types of fixed-abrasive lapping platens with tribochemical action under different abrasive sizes were made. The abrasive is white corundum (aluminum trioxide). The fixed-abrasive lapping platens was shown in Figure 1, and then, the fixed-abrasive lapping platens was pasted on aluminum alloy platen by double-sided glue and put on the lapping and polishing machine with the type ZYP230 made by Shenyang, China, shown in Figure 2. Table 1 is the composition and the content of lapping platen [10, 19, 20, 25-28]. The ferric oxide was selected as the oxidant, the stearic acid was selected as the assistant agent, the molybdenum disulfide was selected as the lubricant and the phenolic resins was selected as the binding agent.

***Tab. 1** Composition and content in tribochemical fixed-abrasive lapping platens*

Name / No.	Abrasive size(μm)	Abrasive content(g)	Oxidant content(g)	Assistant agent(g)	Lubricant content(g)	Other
1	0.5	75.6	45.3	22.6	15.1	Appropriate amount
2	3.5	75.6	45.3	22.6	15.1	Appropriate amount
3	7	75.6	45.3	22.6	15.1	Appropriate amount
4	14	75.6	45.3	22.6	15.1	Appropriate amount

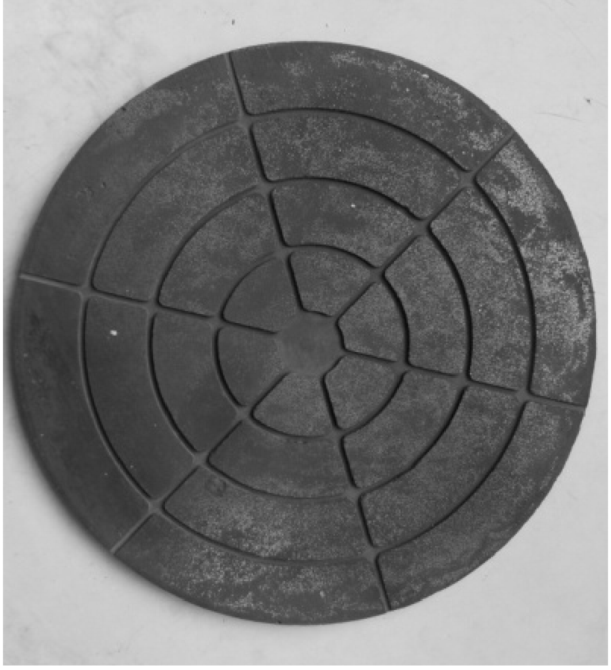

Fig. 1 *Tribochemical fixed-abrasive lapping platens*

All of experiments was be done on the lapping and polishing machine in a super-clean room with cleanness 1000-grade and temperature controlled at 22 ℃. Before the experiment, all of the samples, lapped with 600 mesh sandpaper, were prepared to keep the initial conditions of each sample the same. The surface roughness and morphology of each sample were measured by the Contour GT-K white-light interferometer (Vertical resolution 0.01nm) manufactured by BRUKER, USA. The surface condition of the each sample was observed by Leica DM2500M metallographic microscope (resolution 1 nm). Using the precision electronic balance (accuracy 0.01mg/80g) of Sartorius CP225D, the MRR was calculated by measuring the quality of the 304 stainless steel before and after lapping.

Fig. 2 *The lapping platen is fixed on the lapping machine*

The orthogonal test parameters as shown in table 2 below is carried out using the four types of tribochemical fixed-abrasive lapping platens.

Tab. 2 *Selection of Orthogonal Test Parameters*

Factor	A	B	C	D
	Abrasive size Z(μm)	Lapping pressure P(KPa)	Lapping time T(min)	Lapping speed V(r/min)
1	A1(0.5)	B1(6.895)	C1(15)	D1(30)
2	A2(3.5)	B2(13.790)	C2(30)	D2(50)
3	A3(7)	B3(20.685)	C3(45)	D3(70)
4	A4(14)	B4(27.580)	C4(60)	D4(90)

3 Experimental results and analysis

This experiment has 4 factors and 4 levels, thus 16 groups of orthogonal test tables are selected. The orthogonal test results are shown in the Table 3.

Firstly, the ANOR and calculation of each factor in each index were carried out respectively, and then the analysis results of each index were balanced comprehensively to obtain the optimal test plan.

The calculation results of factor A with each level are as follows.

$$\boldsymbol{K(A,1) = 43.682 + 53.413 + 88.381 + 102.795 = 288.271} \quad (1)$$

$$\boldsymbol{K(A,1)p = K(A,1)/4 = 72.0677} \quad (2)$$

$$\boldsymbol{K(A,2) = 129.365 + 146.286 + 117.062 + 158.062 = 550.775} \quad (3)$$

$$\boldsymbol{K(A,2)p = K(A,2)/4 = 137.6937} \quad (4)$$

$$\boldsymbol{K(A,3) = 167.054 + 168.436 + 189.361 + 202.353 = 727.204} \quad (5)$$

$$\boldsymbol{K(A,3)p = K(A,3)/4 = 181.801} \quad (6)$$

$$\boldsymbol{K(A,4) = 237.337 + 243.131 + 294.543 + 306.385 = 1081.369} \quad (7)$$

$$\boldsymbol{K(A,4)p = K(A,4)/4 = 270.349} \quad (8)$$

Similarly, K(B,j), K(C,j), K(D,j), K(B,j)p, K(C,j)p and K(D,j)p can be obtained. Where i represents the factor, here i=A, B, C, D. j represents the level, here j=1, 2, 3, 4.K represents the index of material removal rate, K (i, j) represents the MRR sum in level j at factor i, K (i, j)$_P$ represents the average values of MRR in level j at factor i. K/ represents the index of surface roughness, K/(i, j) represents the surface roughness sum in level j at factor i, K/(i, j)$_P$ represents the average values of surface roughness in level j at factor i. Table 4 shows these calculation results of the orthogonal test.

Tab. 3 *Orthogonal test results*

No.	Factor				Results	
	A	B	C	D	Material removal rate, MRR(nm/min)	Surface roughness, Ra(nm)
1	0.5	6.895	15	30	43.682	91.659
2	0.5	13.790	30	50	53.413	111.955
3	0.5	20.685	45	70	88.381	117.404
4	0.5	27.580	60	90	102.795	123.404
5	3.5	6.895	30	70	129.365	125.284
6	3.5	13.790	15	90	146.286	137.043
7	3.5	20.685	60	30	117.062	136.128
8	3.5	27.580	45	50	158.062	138.431
9	7	6.895	45	90	167.054	137.795
10	7	13.790	60	70	168.436	129.018
11	7	20.685	15	50	189.361	147.151
12	7	27.580	30	30	202.353	158.383
13	14	6.895	60	50	237.337	184.227
14	14	13.790	45	30	243.131	187.601
15	14	20.685	30	90	294.543	201.725
16	14	27.580	15	70	306.385	226.938

Tab. 4 *Calculation results of various factors*

Index	A	B	C	D
K(i, 1)p	72.0677	144.3595	171.4285	151.5570
K(i, 2)p	137.6937	152.8165	169.9185	159.5432
K(i, 3)p	181.8010	172.3367	164.1570	173.1417
K(i, 4)p	270.3490	192.3987	156.4075	177.6695
ΔRi	198.2812	48.03925	15.0210	26.1125
K/(i, 1)p	111.1055	152.7412	140.6977	143.4427
K/(i, 2)p	134.2215	141.4042	145.3367	145.4410
K/(i, 3)p	143.0867	150.6020	146.3077	150.6610
K/(i, 4)p	200.1227	151.7890	147.1942	159.9917
ΔR/i	89.0172	10.5958	6.4965	16.549

In this paper, the surface roughness and the MRR were mainly studied, because they are the better judge to the lapping quality or lapping effect. So, by the value K(i, j)p, the degree of influence for each factor on MRR can be found, by the value K/(i, j)p, the degree of influence from every factor on the surface roughness also can be obtained. The **ΔRi** and **ΔR/I** represent the different of the average values of MRR and surface roughness in factor i, respectively. By the **ΔRi** and **ΔR/i**, the degree of influence for each factor on surface roughness and MRR also can be found [37-38]. By comparing the **ΔRi** or **ΔR/i**, if the value of **ΔRi** or **ΔR/i** is large, it shows that this factor i has a greater impact on lapping quality or lapping effect, vice versa. According to the test results in Table 4, the relationship between the factors and the levels of K and K/values is drawn, as shown in Figure 3 and Figure 4.

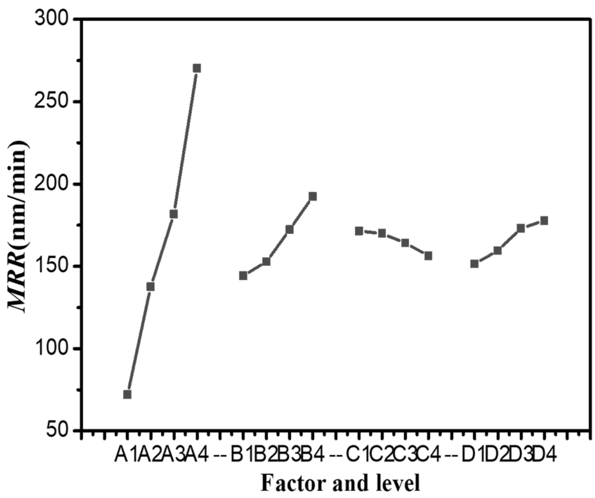

Fig. 3 *Effects of various factors on material removal rate*

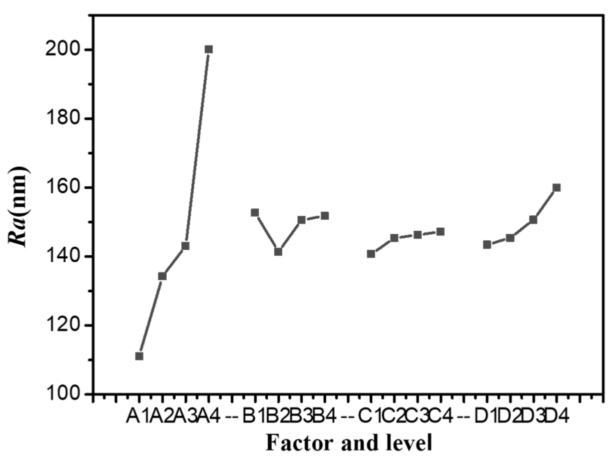

Fig. 4 *Effects of various factors on surface roughness*

By above figures and tables, the analysis result is that the effect orders of each factor on the surface roughness and the MRR are shown as follows.

Fig.3 is the influence degree of each factor on the material removal rate. By the Fig.3, it can be found that the change of abrasive size has a great influence on MRR, when the abrasive size increases from 0.5μm to 14μm, the material removal rate increases from 72nm/min to 270nm/min. The influence degree of other factors is small. So, according to the variation range of the results, the influence degree on the MRR can be determined, it is A>B>D>C. Fig.4 is the influence degree of each factor on the surface roughness. By the Fig.4, the analysis method is the same as that in Fig. 3, it can be obtained that the degree of influence on the surface roughness is A>D>B>C.

From the above orders, Fig.3 and the Fig.4, it can be seen that the size of abrasives has the largest influence on the surface roughness and the MRR in lapping 304 stainless steel with tribochemical fixed-abrasive lapping platen. All of the surface roughness and the MRR increases with the increase of abrasive size. Lapping time has little effect on the surface roughness and the MRR. Influences are that the MRR decreases slowly and the surface roughness increases slightly with the increase of lapping time. The influence on the surface roughness and the MRR, the rotational speed of the lapping platen is different with the lapping pressure. The surface roughness and the MRR increase gradually with the increase of rotational speed of the lapping platen, but with the increase of lapping pressure, the MRR increases gradually and the surface roughness decreases first and then increases. Due to the tribochemical action, there may be an optimal pressure to optimize the interaction between tribochemical action and abrasive removal and maximize the material removal rate.

According to the trend reflected in the chart and table, in order to get a larger MRR, the combination of factors is selected the A4B4C1D4, that is, when abrasive size is 28μm, lapping time is 15 minutes, rotational speed of lapping platen is 90r/min and lapping pressure is 27.580 KPa, the maximum MRR is 412.524 nm/min after lapping experiment. For the reason that the lower surface roughness, the combination of factors is selected the A1B2C1D1, that is, when the abrasive size is 0.5μm, the rotational speed of lapping platen is 15 r/min, the lapping pressure is 13.790 KPa and the lapping time is 15 minutes, the surface roughness drops to 41nm after lapping experiment.

4 Discussion

4.1 Influence of abrasive size on surface roughness and MRR

Because the stainless steel material belongs to the plastic material, in lapping, the material removal is mainly caused by the compound action of the extrusion, the scratching and ploughing produced by abrasives and the lapping platen on the workpiece surface. The removal of surface material belongs to two-body wear [39-40].

By these research results above mentioned, the MRR is in proportion to the rotational speed of the lapping platen and the abrasive size, and in proportion to the lapping pressure P or $P^{1/3}$ or $P^{2/3}$ [41-42].

By the research result of Li [43], the surface roughness is directly proportional to the abrasive size and the lapping pressure $P^{1/3}$, and Yeruva [44] also considered that the surface roughness is directly proportional to the abrasive size and the lapping pressure $P^{2/3}$.

Other researchers also think that with the increase of abrasive size, the surface roughness of workpiece increases exponentially [45-47].

In a word, a certain normal pressure will be loaded during the lapping process. When the quality of each abrasive is equal in fixed abrasive lapping platen, the number of abrasives contained in the lapping platen per unit mass decreases with the enlarge of the abrasive size, but the pressure loaded on a single abrasive increase with the decrease of the number of abrasive. So, the extrusion effect, the scratching action of one abrasive on the surface of workpiece is large, and this will lead to the increase of the cutting force and the cutting ability of abrasive, and cause the MRR increase. At the same time, the depth of the abrasive embedded into the workpiece surface and the length of the contact arc with the workpiece surface of the abrasive increase with the enlarge the abrasive size, and this will lead to the greater of the surface roughness [48]. Under the same normal pressure, when the abrasive size changes smaller, the number of abrasives contained in the unit mass lapping platen will increase and the number of effective abrasives actually involved in the lapping process will also increase. This will lead to the more uniform of the cutting effect, the lower of the surface roughness on the material surface is and the better of the surface quality.

4.2 Influence of lapping pressure on surface roughness and MRR

According to Section 4.1, the lapping process of the workpiece mainly depends on the scratching and cutting effect of the abrasive fixed on the lapping platen. When other parameters are unchanged, the smaller the normal pressure is, the smaller the cutting force of the abrasive on the workpiece is, the smaller the depth of a single abrasive embedded in the workpiece is, and the lower the surface roughness and the MRR are. When the lapping pressure increases, the pressure on the working abrasives increases, and the depth of abrasives pressed into the workpiece surface increases, therefore, the ploughing effect of abrasives on the workpiece surface increases, and the MRR increases [49]. In addition, with the increase of the lapping pressure, the friction force between the workpiece and the lapping platen increases, and the friction chemical reaction can increase, which also can promote the MRR. Therefore, the MRR and surface roughness increase with the increase of lapping pressure. This conclusion is consistent with the research results of literatures.

4.3 Influence of lapping platen speed on MRR and surface roughness

According to Section 4.1, when the normal lapping pressure is not changed, the cutting force of the abrasive on the workpiece is not changed. The lower the rotational speed of the lapping platen is, the shorter the contact length of the single abrasive on the workpiece surface in unit time is, and the shorter the scratch length of the total abrasives on the workpiece surface is, so the lower the MRR is. With the increase of the rotation speed of the lapping platen, the contact times between single abrasive and workpiece surface increase, the cutting path length of the total abrasives increases, so, the MRR increases. But, when the normal lapping pressure is constant, the cutting force and cutting depth of the abrasive is constant basically, so the rotation speed of lapping platen has less influence on the surface roughness.

4.4 Influence of lapping time on surface roughness and MRR

In the lapping process, with the increase of lapping time, most abrasives on the lapping platen become gradually blunt and the cutting ability of the abrasive is reduced, which will result in the decrease of MRR. In addition, with the increase of lapping time, on the surface of the lapping platen, the lapping waste and debris accumulated increase, which may participate in the lapping, this will affect the normal process of lapping and lead to the larger of surface roughness. This is the reason that the lapping platen must be conditioned after lapping for a certain time.

5 Conclusion

In this paper, the surface roughness and the MRR were mainly studied by lapping the 304 stainless steel using the tribochemical fixed-abrasive lapping platen developed by our research group. The conclusions are as follows.

The influence degree on the MRR from better to worse is the abrasive size, the lapping pressure, the rotation speed of lapping platen and the lapping time. The influence degree on the surface roughness from better to worse is the abrasive size, the rotation speed of the lapping platen, the lapping pressure and the lapping time.

In lapping process, the material removal of the 304 stainless steel is mainly caused by the compound action of the extrusion, the scratching and ploughing produced by abrasives of the tribochemical fixed-abrasive lapping platen.

The abrasive size has the greatest influence on the surface roughness and the MRR, and the MRR and surface roughness increase with the increase of abrasive size. Lapping time has less effect on lapping results. The surface roughness increases slightly and the MRR decreases slowly with the increase of lapping time.

When the lapping pressure increases, the mechanical action of abrasives increases, and then, the surface roughness and the MRR increase. When the increase of the rotation speed of the lapping platen, the cutting path length of the total abrasives increases, so the MRR increases, but the rotation speed of lapping platen has less effect on the surface roughness.

Acknowledgements

The authors acknowledge the financial support of the Science and Technology Research Project of Henan Province (No.192102210058) and the National Natural Science Foundation of China (No.U1804142).

References

[1] LOGOTHETIDIS S., LASKARAKIS A. (2009). Towards the optimization of materials and processes for flexible organic electronics devices. *The European Physical Journal-Applied Physics*, 46(1): 12502. https://doi.org/10.1051/epjap/2009041

[2] HANADA T., NEGISHI T., SHIROISHI I., SHIRO T. (2010). Plastic substrate with gas barrier layer and transparent conductive oxide

thin film for flexible displays. *Thin Solid Films*, 518(11): 3089-3092. https://doi.org/10.1016/j.tsf.2009.09.166

[3] LEE S., HAN J. H., LEE S. H., BAEK G. H., PARK J. S. (2019). Review of Organic/Inorganic Thin Film Encapsulation by Atomic Layer Deposition for a Flexible OLED Display. *Journal of metals*, 71: 197-211. https://doi.org/10.1007/s11837-018-3150-3

[4] WU W.J., CHEN J.W., WANG J.S, ZHOU L., TAO H., ZOU J.H., XU M., WANG L., PENG J.B., CHAN M.S. (2018). High-Resolution Flexible AMOLED Display Integrating Gate Driver by Metal-Oxide TFTs. *EEE Electron Device Letters*, 39(11): 1660-1663. DOI: 10.1109/LED.2018.2871045

[5] HONG K., YU H. K., LEE I., KIM S., KIM Y., KIM K., LEE J. L. (2018). Flexible top-emitting organic light emitting diodes with a functional dielectric reflector on a metal foil substrate. *RSC Advances*, 8: 26156-26160. DOI: 10.1039/C8RA05759A

[6] FENG W.L., HUANG P. (2012). Advances in flexible displays substrates. *Chinese Journal of Liquid Crystal and Display*, 27(5): 599-607

[7] YANG L. Y., YIN S. G., HUA Y. L., LU Y., WANG C., DONG B. (2006). Flexible Substrates and Encapsulation Methods for Flexible Organic Light Emitting Devices. *Journal of Functional Materials*, 37(1): 10-13

[8] DUAN L., ZHANG C., ZHANG G.H. (2010). Prepartion and behavior of flexible organic light emitting diodes. *China Sciencepaper*, 5(4): 287-290

[9] LIU H. Y. (2009). Performance and Test of Glass Substrate for TFT-LCD. *Glass*, 36(1): 22-24

[10] LIU Z.H., CHEN S.K., PENG Y.M., LI J.J., SU J.X. (2018). Compositions of slurry used in chemical-mechanically polishing 304 stainless steel. *Diamond & Abrasives Engineering*, 38(2): 78-81+88. DOI: 10.13394/j.cnki.jgszz.2018.2.0016

[11] SUGIMOTO A., OCHI H., FUJIMURA S., YOSHIDA A., MIYADERA T., TSUCHIDA M. (2004). Flexible OLED displays using plastic substrates. *IEEE Journal of Selected Topics in Quantum Electronics*, 10(1): 107-114. DOI: 10.1109/JSTQE.2004.824112

[12] BARDSLEY J. N. (2004). International OLED technology roadmap. *IEEE Journal of Selected Topics in Quantum Electronics*, 10(1): 3-9. DOI: 10.1109/JSTQE.2004.824077

[13] YAMADA N., OGURA T., KUBO Y., NAGASAKI S. (2009). Stainless steel foil for flexible display [P]. CN102026743A, May 13

[14] ZARDETTO V., BROWN T. M., REALE A., DI CARLO A. (2011) Substrates for flexible electronics: A practical investigation on the electrical, film flexibility, optical, temperature, and solvent resistance properties. *Journal of Polymer Science Part B: Polymer Physics*, 49(9): 638-648. https://doi.org/10.1002/polb.22227

[15] SOMEYA T. (2010). Flexible electronics: Tiny lamps to illuminate the body. *Nature Materials*, 9: 879-880. https://doi.org/10.1038/nmat2886

[16] SUN Y.Y., HUA Y.L., YIN S.G., FENG X.L., ZHENG J.J., WANG S.G. (2005). Flexible organic light emitting material and devices. *Journal of Functional Materials*, 36(2): 161-164

[17] SPECIAL STEEL ENTERPRIES ASSOCIATION OF CHINA (2019). Uultra-thin stainless steel precision strip for flexible display screen. *China Special Steel Enterprises Association Announcement for Group Standards and Codes*

[18] ERITT M., MAY C., LEO K., TOERKER M., RADEHAUS C. (2010). OLED manufacturing for large area for lighting application. *Thin Solid Films*, 518(11): 3042-3045. https://doi.org/10.1016/j.tsf.2009.09.188

[19] CHEN J.P. (2016). Study on ultra-thin SUS304 stainless steel polishing fluid for chemical mechanical polishing. College of Mechanical and Power Engineering, Henan University of Technology. Doi: 10.7666/d.D01064104

[20] LI Q., CHEN S.K., PENG Y.N., QIN H.Q., FU S.F., SU J.X. (2016). Chemical mechanical polishing process parameters of 304 stainless steel. *Diamond & Abrasives Engineering*, 36(5): 21-25. DOI: 10.13394/j.cnki.jgszz.2016.5.0004

[21] XIE Z. Y., HUNG L. S., ZHU F.R. (2003). A flexible top-emitting organic light-emitting diode on steel foil. *Chemical Physics Letters*, 381(5): 691-696. DOI: 10.1016/j.cplett.2003.09.147

[22] DESHPANDE L. S., RAMAN S., SUNANTA O., AGBARAJI C. (2008). Observations in the Flat Lapping of Stainless Steel and Bronze. *Wear*, 265(1-2): 105-116. https://doi.org/10.1016/j.wear.2007.09.004

[23] ZHU C. R., LV B. H., YUAN J. L. (2010). Influences of Properties of Fixed Abrasive Tool

on the Lapping Process of Stainless Steel Substrate. *Advanced Materials Research*, 135: 365-369. https://doi.org/10.4028/www.scientific.net/AMR.135.365

[24] ZHU C.R., LV B.H., YUAN J. L. (2012). Influence of Bond Material Concentration on the Mechanical Properties of Fixed Abrasive Lapping Tool for Stainless Steel. *Key Engineering Materials*, 499: 372-377. https://doi.org/10.4028/www.scientific.net/KEM.499.372

[25] SU J.X., CHEN J. P., LI Q., QIN H.Q. (2016). Study on Slurry of Chemical Mechanical Polishing 304 Stainless Steel Based on Ferric Chloride and Oxalic Acid. *Material Science Forum*, 861: 102-107. https://doi.org/10.4028/www.scientific.net/MSF.861.102

[26] SU J.X., LI J.J., WANG Z.K., LI Y.F., LIU L.L. (2017). Chemical action in CMP 304 stainless steel based on hydrogen peroxide slurry. *Acta Technica*, 62(4B): 1-12

[27] SU J.X., PENG Y.A., LIU Z.H., LI J.J., CHEN J.P., LI Y.F. (2017). Study on the pH Value Regulator of Ferric Chloride Based Slurry in Chemical Mechanical Polishing 304 Stainless Steel. *U.P.B. Stiintific Buletin, Series B*, 79(2): 179-190.

[28] FAN S. Z., FU S. F., YAO J. G., MA L.J., SU J.X. (2014). Design of lapping paste in lapping 304 ultra-thin stainless steel sheet. *Advanced Materials Research*, 1027: 93-96. https://doi.org/10.4028/www.scientific.net/AMR.1027.93

[29] HEINICKE G. (1964). Wissenschaft und Fortschritt, 14: 163-168

[30] LUO Q.F., LU J., XU X.P. (2016). A comparative study on the material removal mechanisms of 6H-SiC polished by semi-fixed and fixed diamond abrasive tools. *Wear*, 350-351: 99-106. https://doi.org/10.1016/j.wear.2016.01.014

[31] HARA H., SANO Y., MIMURA H., ARIMA K., KUBOTA A., YAGI K., MURATA J., YAMAUCH K. (2006). Novel abrasive-free planarization of 4H-SiC, No.0001) using catalyst. *Journal of Electronic Materials*, 35: L11-L14. https://doi.org/10.1007/s11664-006-0218-6

[32] HARA H., SANO Y., MIMURA H., ARIMA K., KUBOTA A., YAGI K., MURATA J., YAMAUCHI K. (2007). Novel abrasive-free planarization of Si and SiC using catalyst. *Towards Synthesis of Micro/Nano Systems*, 267-270. DOI: 10.1007/1-84628-559-3_45

[33] ZHANG P. (2017). Research on the Key Technologies of Ultra Precision Polishing of Silicon Carbide Single Crystal Substrate. Shandong University

[34] FAN P. F., ZHAI W. J. AND ZHANG X. X. (2016). Effects of Electric Potentials on Tribological Properties of SiC/HT200 Pairs in NaOH Solutions. *Journal of Harbin Institute of Technology (New Series)*, 23(3): 75-79

[35] SU J. X., ZHANG X. M., WAN X.Y., FU S.F. (2014). Study on Fixed Abrasive Lapping SiC Single Crystal Substrate (0001) C Surface. *Nanotechnology and Precision Engineering*, 12(6): 417-423. DOI: 10.13494/j.npe.20140046

[36] LI B., LI J., GAO P., ZHU Y.W., LUO H.J., ZUO D.W. (2013). Study on Depth of Subsurface Crack Layer by Free and Fixed Abrasive Lapping. *China Mechanical Engineering*, 24(7): 895-898+905

[37] QUAN W., HU Z.Q., CHERNEGA S.M., MA J. (2009). Aluminum alloy surface of micro-arc oxidation coating preparation process design. *Light Alloy Fabrication Technology*, 37(12): 45-48+57

[38] HU Y.P., ZHUO L.S., WANG C.Z., ZHAO G., CHEN D.Y., SHEN Y.D. (1989). Decide technique parmeters for designing and applying turning shaping equipment of crush roll. *Journal of Anhui Institute of Technology*, 4: 29-42

[39] WANG Y., ZUO Y. S., JIN Z. J. (2015). Analysis of Material Removal Rate in Lapping of the Hard Alloy Rings. *Mechanical Engineering and Technology*, 4(2): 127-134. DOI: 10.12677/MET.2015.42013

[40] LUO J.F., DORNFELD A.D. (2001). Material removal mechanism in chemical mechanical polishing: Theory and modeling. *IEEE Transactions on Semiconductor Manufacturing,* 14(2): 112-133. DOI: 10.1109/66.920723

[41] PRESTON W. (1927). The Theory and Design of Plate Glass Polishing Machine. *Journal of Glass Technology*, 11(44): 214-256

[42] SUN Y.Y., SHANG C.M. (2017). Modeling and Simulation Study on Material Removal Rate of Consolidation Abrasive Grinding. *Automobile Parts*, 12: 34-37. DOI: 10.19466/j.cnki.1674-1986.2017.12.008

[43] LI J., WANG H.M., WANG W. Z., HUANG J.D., ZHU Y.W., ZUO D.W. (2015). Model of Surface Roughness in Fixed Abrasive Lapping of K9 Glass. *Journal of Mechanical Engineering*, 51(21): 199-205

[44] YERUVA S. B. (2005). Particle scale modeling of material removal and surface roughness in chemical mechanical polishing. University of Florida

[45] CHEN M. J., ZHANG F.H., DONG S., LI D. (2001). Study on ultra-precision grinding of optical glasses in the ductile mode. *Chinese Mechanical Engineering*, 4: 460-463+484

[46] WANG X., ZHANG X. J. (2009). Micro theoretical model for grinding SiC mirror with fixed abrasive. *Optics and Precision Engineering*, 17(3): 513-518

[47] LUO R., XU L.M., CHA T.J., YANG Z.Q., SHI L., HU D.J. (2013). Modeling and simulation of surface roughness for spherical grinding. *Journal of Shanghai Jiaotong University*, 47(5): 709-714. DOI: 10.16183/j.cnki.jsjtu.2013.05.005

[48] RUBEŠOVÁ K., PEKOVIĆ M., JIRKOVÁ H., HRADIL D. (2021). Resistance of tool steel processed by unconventional forming technology against abrasive wear. *Manufacturing Technology*, 21(2): 241-246. DOI: 10.21062/mft.2021.028

[49] FARSKÝ J., BAKŠA T., ZETEK M. (2020). Grinding of maraging steel 1.2709 with SiC grinding wheels and effect of grinding conditions on the surface roughness and wear of the wheels. *Manufacturing Technology*, 20(1): 18-22. DOI: 10.21062/mft.2020.018