The Analysis Is for the Design of Different Club Face's Thicknesses of Fairway Wood to the Characteristic Time

Fairway Wood to the Characteristic Time

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***Abstract*—The club face of fairway wood is processed through the iron alloy heating procedure and CNC to innovate the club head with high spring-like effect (characteristic time). (1) Use 455 stainless steel processed by heating and aging treatment, to do the analysis on microstructure and mechanical properties. (2) Through CNC to design seven different patterns for the back of club face, each pattern for three club head. The total amount is twenty-one. (3) Make finished product be test the characteristic time and the ability of strike by the practical measurement. (4) To analyze after the compare between three-way ANOVA and LSD. After 455 stainless steel was heated in procedure S850℃-A550℃, mechanical properties became superior and had the better malleability, it is suitable for developing the club face of high spring-like effect. Before and after grinding among three-way ANOVA (pattern*thickness*place), did not achieve the significant level on the figure of characteristic time. Through two-way ANOVA (pattern*place and thickness*place), showed the significant deviation before and after grinding. After doing the crash test by 45m/s, all the results can reach the higher limited standard. 455 stainless steel was designed with the different club face's thicknesses of fairway wood can make spring-like effect achieve high characteristic time.**

Keywords—club head; heating procedure; mechanical properties; microstructure; stainless steel

I. INTRODUCTION

A lower score is sought in golf, and previous studies showed that stable control and driving distance are the foremost abilities [2,3,5,10,11,14,15]. Therefore, every golfer has an intense motive to achieve a driving distance over 300 yards, where the longer the distance, the better the self-confidence and sense of superiority, and the higher the satisfaction with their equipment, which is key for the high profits of equipment manufacturers. As clubs are continuously improved, a good driver makes the average driving distance of professional players longer than 300 yds. In the last ten years, there is slight difference among ordinary golfers, thus, the level of difficulty of the original course design is reduced, which removes the fun of the challenge and technical performance in golf. Therefore, the United States Golf Association (USGA) and Royal and Ancient (R&A), which lead golf development, set new club head specifications in 2004, and specified that the Coefficient of Restitution (COR) of a driver during a strike should not exceed 0.83, meaning higher than 0.83 should not be used in the game. Afterwards, the USGA and R&A indicated that COR testing was a type of measurement that damaged the structure, as the shaft must be detached from the club head, and the structure of the ball and the flight speed before striking could influence the COR data, leading to distortion. Therefore, the USGA and R&A proposed another testing method in 2009: Characteristic Time (CT), which replaces the original COR value. CT is also known as contact time, the quantitative standard of CT is 239μs and the error value is ±18μs, thus, the acceptable maximum value is 257μs [12]. However, this restriction is limited to the driver, while fairway woods and iron clubs are free from such restriction.

However, in the present equipment design and material science, the theory and technology of the CT value control method are not yet effectively mastered. It is generally recognized that the CT value is related to the club face thickness and striking position. As the CT value performance is restricted, in order to enhance the strike performance of general golfers, equipment manufacturers increased the output value, and actively engage in designing a high CT value club head. The findings of Dear [1] indicated that the ball out speed is increased by about 5km/h when the COR is increased by 5%, and the driving distance is 8 to 12 yards. The findings of Peng [4], Kuo and Chao [6] showed that the striking face thickness is significantly related to the CT value. In addition, the mechanical strength of the material is positively related to CT value. The tensile strength, yield strength, elongation, and hardness of mechanical properties must be appropriately combined during equipment design and development, in order to manufacture a club head with the optimum performance and make higher profits

[6,9]. However, the thinner the club face, the higher the mechanical strength required, thus, the selected alloy material must have light weight and high specific strength (tensile strength/density). Therefore, clubs on the market are mostly made of lightweight Ti alloy material with high specific strength; however, the defect is the high cost, meaning a club fully made of Ti alloy is very expensive, which results in difficult marketing. Therefore, commercially available club brands seek ferrous alloy materials with high strength, or use physical heat treatment to improve the original alloy structure and increase alloy strength; as Ferrous alloy with high specific strength is developed, costs are reduced and performance is close to Ti alloy. Thin club face can be made, and the spring-like effect of the club face is enhanced, such as Honma and PXG brands.

According to the findings, the performance of the spring-like effect (CT) is influenced by the mass of the club head, the thickness of the striking face, the mechanical properties, and the material process. At present, in order to increase the spring effectiveness of a club head, equipment manufacturers mostly use materials with high strength, low elongation percentage, and low density, thus, the striking face is light and thin (Ti alloy). Therefore, this study aims to design a fairway wood with high-CT club face. As the Ti alloy material used by equipment manufacturers is costly, in order to reduce costs, most fairway woods are made of ferrous alloy to increase profit. The design of the fairway woods available on the present market aim at low center of gravity, handiness, and low miss ratio, and the CT value performance is about 220μs. If the CT value performance is improved through innovative club face design, driving distance can be increased, and if the price is low, higher profit will be created for the industry. Therefore, with the main material of ferrous alloy stainless steel, this study aims to develop a fairway wood free from the CT value specification, design a high-CT fairway wood, and reduce costs. To sum up, the purpose of this study is to make a fairway wood with high CT value. The mechanical properties of the alloy material are improved and nonuniform club face thickness is designed for handiness, as well as stable and farther driving distance, and the cost is controlled, thus, users can maintain controllability and long distance, and equipment manufacturers are more competitive and innovative to make higher profits.

II. METHODS

A. SUBJECTS

This study takes 455SS stainless steel as the subject alloy material, which is characterized by high strength, corrosion resistance, and low unit price, while the mechanical properties of the club face can be enhanced by different heating procedures and aging treatment processes, thus, industrial circles will be sophisticated to some extent. In addition, in order to enhance CT value performance, the patterns designed by the researcher are completed by a CNC milling machine on the back of a striking face made of 455SS alloy, where the purpose is to reduce the partial area to increase CT value. The best mechanical properties after the heating procedure of the alloy material for making the club head sample are the sample specifications.

B. METAL HEATING PROCEDURE

The heating procedure is implemented in an atmospheric environment. First, the Custom 455 plate is made into a tensile bar, which is made into a tensile specimen and put in a high temperature furnace for solid solutions at different solid solution temperatures of 850℃, 900℃, 950℃, 1000℃, and 1050℃. After 30 minutes' heating, the material is placed in water at normal temperature for water cooling, and after 4 hours' aging treatment at 550℃.

C. MECHANICAL STRUCTURE ANALYSIS

The tensile testing (tensile strength, yield strength, and elongation percentage) and hardness testing are conducted to determine the mechanical strength of the 455SS alloy material.

D. MICROSTRUCTURE OBSERVATION AND ANALYSIS

The key instrument systems for observation and analysis include an optical microscope (OM) and Scanning Electron Microscopy (SEM).

E. GRAIN ANALYSIS

According to the ASTM E112 standard specifications, the method to calculate the mean grain size on a metallography uses the intercept method. First, a screen sheet as large as the metallography is prepared, and several "horizontal", "vertical", and "45° oblique" straight lines are drawn on it, then the screen sheet covers the metallography. The number of grains in each straight line is calculated, and the straight length and the corresponding number of grains are recorded. Finally, the obtained data are substituted in the following computing equation to obtain the grain size. Among the material enhancement methods, only grain refining can simultaneously enhance material strength and ductility. The material strength increases as the grain size decreases. When the grain is small, the dislocation can easily slip over the grain to reach the grain boundary, meaning the dislocations are likely to pile up at the grain boundary and uniformly deform the interior of the grain; as there are many grains, and each grain has a different orientation, there are many orientations for slip to implement uniform deformation, leading to higher ductility. The grain boundary can be regarded as a result of dislocation pile-up. The grain boundary strength is higher than the intragranular strength at a low temperature, thus, the material can be enhanced by increasing the grain boundaries.

$$D = (L/d) \times (1/P) \tag{1}$$

D is grain size, L is the measured total length, d is the number of grains through, p is the magnification

$$\sigma = \sigma_0 + \kappa_\gamma \times D^{-1/2} \tag{2}$$

Where σ is the strength, D is the mean grain diameter, and Ky is a constant.

F. CLUB FACE DESIGN AND ANALYSIS

The accuracy of the striking faceplate is controlled by a CNC comprehensive center machine tool and CAM/CAD software (UG), while the thickness of the striking faceplate is controlled by HSM. The pendulum test (CT) and strike resistance test (striking durability analysis) results are shown in Figure 1; all testing processes conform to USGA and R&A specifications.

G. PATTERN DESIGN

The researcher designs combinational geometry, and the back of the striking face is machined by a CNC milling machine. There are 7 patterns designed (Table 1) for the club head, and three experimental club heads are made from each pattern for analysis.

H. DATA ANALYSIS AND STATISTICAL

All the parameters obtained by experimentation are analyzed by EXCEL and SPSS 22.0 software.

1. The metal heating procedure, mechanical structure testing, pendulum testing (CT), and strike resistance testing (striking durability analysis) are assigned to O-TA Precision Industry Co., Ltd. The accuracy of the striking faceplate is controlled by a CNC comprehensive center machine tool and CAM/CAD software at Xiesheng Industrial. Microstructure observations and grain analysis are provided and assisted by the Precision Instruments Center, National Sun Yat-sen University.

2. The mechanical properties and microstructure parameters of the 455SS material at different heat treatment temperatures are displayed by descriptive statistics.

3. The performances of the CT parameters of the different striking face thicknesses and pattern designs are compared by mixed design three-way (thickness x position x pattern) variance. When the three-way interaction is significant, the simple main effect is analyzed. If the three-way interaction is not significant, the two-way test is implemented. If the two-way interaction is significant, the simple main effect is analyzed. In addition, when the interaction is not significant, the main effect is analyzed. The significance levels of all statistical tests are defined as α=.05.

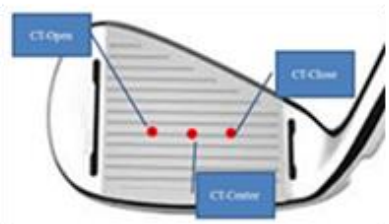

Figure 1. Testing positions for CT and striking resistance tests.

Table 1. Striking face back pattern design.

No.	Pattern	No.	Pattern	No.	Pattern	No.	Pattern
1		3		5		7	
2		4		6			

III. RESULTS

A. ANALYSIS OF MECHANICAL PROPERTIES OF 455SS ALLOY MATERIAL

Table 2 shows the distribution of the mechanical properties of 455SS after different heating procedures and aging treatments, including grain size, hardness, tensile strength, yield strength, and elongation percentage. The tensile strength decreases from 154.8 ksi to 147.2 ksi as the solid solution temperature of the heating procedure rises. The yield strength is 140.8 to 143.8 ksi. The elongation percentage is 11.72 to 12.65%. The hardness decreases from 28.5 to 27.0 HRc as the solid solution temperature of the heating procedure rises, and the grain size increases with the temperature of the solution treatment. The 455SS is cooled by water after the temperature is maintained at 850℃ for 30 minutes, and cooled by water after the temperature is maintained at 550℃ for 4 hours, in order to have the smallest grain size of 12.34μm. When the heat treatment conditions are water cooled after 30 minutes' solution treatment at 1050℃ and water cooling after 4 hours' treatment at 550℃, the grain size increases to 58.11μm (Figure 2).

Table 2. Mechanical properties of 455SS alloy material after heating procedure at different temperatures.

Condition	Ts(ksi)	Ys(ksi)	E(%)	HRc	Grain size(*μm*)
S850℃-A550℃	154.8	143.8	11.72	28.5	12.34
S900℃-A550℃	153	142.5	12.44	28.7	15.89
S950℃-A550℃	150.3	143.5	12.49	27.9	21.77
S1000℃-A550℃	148.9	141.7	12.65	26.9	39.88
S1050℃-A550℃	147.2	140.8	11.91	27	58.11

PS. S solution treatment, A aging treatment 5. Patents.

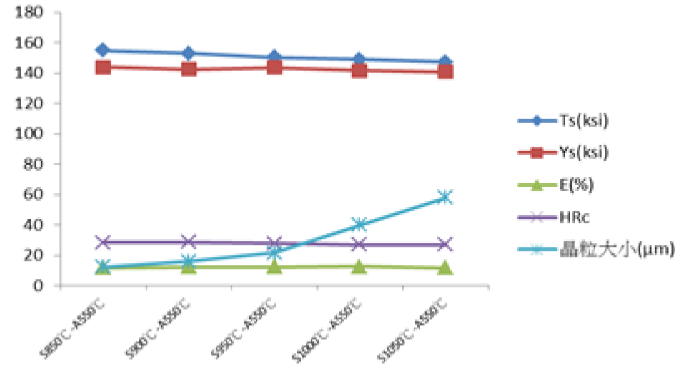

Figure 2. Mechanical properties of 455SS alloy material after heating procedure at different temperatures.

B. 455SS MICROSTRUCTURE ANALYSIS

Figures 3 to 7 show the SEM images of 455SS after solution treatment and aging treatment, including water cooling after 30 minutes' solution treatment at 850 ℃ and water cooling after 4 hours' solution treatment at 550℃; water cooling after 30 minutes' solution treatment at 900℃ and water cooling after 4 hours' solution treatment at 550℃; water cooling after 30 minutes' solution treatment at 950℃ and water cooling after 4 hours' solution treatment at 550℃; water cooling after 30 minutes' solution treatment at 1000℃ and water cooling after 4 hours' solution treatment at 550℃; water cooling after 30 minutes' solution treatment at 1050℃ and water cooling after 4 hours' solution treatment at 550℃. The structures are basically acicular structures, meaning the heat treatment temperature has slight effect on the microstructure.

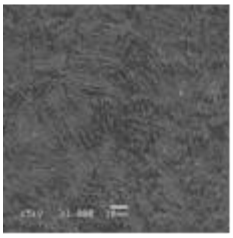

Figure 3. 850℃.

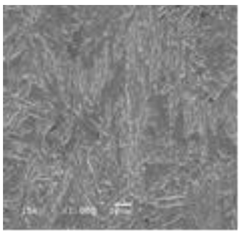

Figure 4. 900℃.

Figure 5. 950℃.

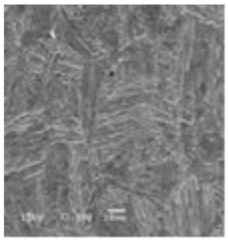

Figure 6. 1000℃.

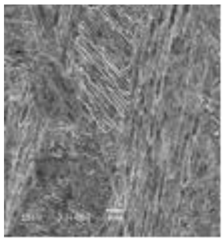

Figure 7. 1050℃.

C. CLUB HEAD STRIKING FACE ANALYSIS

1) THICKNESS

Table 3 shows the club head numbers of the various schemes, as well as the results of the average thicknesses of the club faces, as measured by an ultrasonic thickness gauge, including the pretest values and the measured values after grinding 0.1mm. As it is ground manually, there are partial errors, thus, not every club head's striking face thickness is accurately reduced by 0.1mm. There are three pieces for each pattern, and three measuring points according to the golfer's striking positions, which are CT-open, CT-center, and CT-close. The results of the actual measurements show that the striking faces are within the controlled 0.1mm gap.

Table 3. Pre-test and post-test average thickness values of different striking face designs (unit: mm).

Style	Pre-test CT-open (SD)	Pre-test CT-center (SD)	Pre-test CT-close (SD)	Post-test (-0.1mm) CT-open (SD)	Post-test (-0.1mm) CT-center (SD)	Post-test (-0.1mm) CT-close (SD)
1	2.03(0.01)	1.98(0.03)	2.02(0.07)	1.92(0.05)	1.86(0.03)	1.92(0.01)
2	2.02(0.04)	1.96(0.02)	2.00(0.03)	1.88(0.09)	1.86(0.02)	1.88(0.06)
3	2.02(0.01)	2.02(0.04)	2.08(0.06)	1.90(0.01)	1.90(0.02)	1.95(0.02)
4	2.06(0.04)	1.98(0.04)	2.10(0.02)	1.93(0.03)	1.87(0.02)	1.93(0.05)
5	2.02(0.01)	1.99(0.01)	2.05(0.01)	1.92(0.03)	1.89(0.01)	1.99(0.02)
6	2.01((0.04)	1.99(0.04)	2.09(0.03)	1.88(0.02)	1.87(0.02)	1.98(0.02)
7	2.04(0.04)	1.98(0.03)	2.02(0.03)	1.95(0.06)	1.92(0.02)	1.91(0.08)

PS. L: LEFT, C: CENTER, R: RIGHT; (SD) = STANDARD DEVIATION

2) CT PERFORMANCE

Table 4 shows the striking face CT values of the various club heads, as measured by a pendulum tester. Three pendulum speeds are used according to USGA and R&A specifications, struck three times at each speed, the CT values are calculated by the system's built-in equation. There are three club heads for each pattern, and the measurement points are CT-open, CT-center, and CT-close according to the actual golfer's striking positions. In order to reduce measurement errors, each club head is measured once at intervals of one day by the same person, and they are measured three times. The obtained data are averaged, and the results of mixed design three-way ANOVA are shown in Table 5.

According to Table 5, the three-way (pattern * thickness * position) interaction has not reached the significance level (F=0.542, p>.05) before or after grinding in the CT values of the different striking face designs. Therefore, the two-way interaction term is tested. According to Table 5, the interaction of pattern (A) and striking position (C) (F=1.942, p<.05) in the CT value performance reaches the significance level; and the interaction of thickness (B) and striking position (C) (F=55.875, p<.05) in the CT value performance reaches the significance level. In addition, at different thicknesses, the striking face CT value after grinding is significantly better than that before grinding (F=113.451, p<.05). In different strike positions, the CT value performance after grinding is also better than that before grinding, reaching a significant difference level (F=58.312, p<.05), meaning the thinner striking face has better CT value performance, and is free from the striking spot, meaning the CT value represents the spring-like effect, thus, the results show that the thinner striking face has better spring-like effect.

Table 4. Statistical table of mean CT before and after grinding of different striking face designs.

Style	Pre-test CT-open (SD)	Pre-test CT-center (SD)	Pre-test CT-close (SD)	Post-test (-0.1mm) CT-open (SD)	Post-test (-0.1mm) CT-center (SD)	Post-test (-0.1mm) CT-close (SD)
1	194(6.1)	245(8.0)	194(2.1)	202(5.0)	252(21.9)	239(29.0)
2	197(3.7)	237(3.1)	197(1.7)	203(4.5)	255(12.8)	242(19.1)
3	191(2.3)	241(17.6)	183(4.0)	201(8.7)	257(8.0)	261(8.5)
4	191(3.7)	220(3.1)	199(2.6)	196(1.0)	241(1.5)	255(37.8)
5	187(4.7)	222(6.6)	186(17.3)	196(5.5)	239(3.4)	246(13.4)
6	191(3.2)	216(10.1)	195(3.6)	199(6.5)	238(3.7)	265(8.6)
7	201(2.8)	223(6.6)	204(5.2)	203(2.6)	236(3.4)	241(41.5)

PS. L: left, C: center, R: right; (SD) = Standard deviation

Table 5. Three-way mix design analysis abstract of back pattern, thickness, and striking position in CT value.

Source of variation	SS	df	MS	F value
Between-subjects				
Pattern (A)	1075.762	6	179.294	0.906
Thickness (B)	22453.365	1	22453.365	113.451*
Pattern*thickness (A) * (B)	1197.190	6	199.532	1.008
Within-group (error)	5541.556	28	197.913	
Within-subjects				
Position (C)	34691.492	2	17345.746	106.155*
Pattern*position (A*C)	3807.619	12	317.302	1.942*
Thickness*position (B*C)	14093.397	2	7046.698	43.125*
Pattern*thickness* position(A*B*C)	1077.048	12	89.754	0.549
Within-group (error)	9150.444	56	163.401	

PS: *p<.05

The three-way (pattern * thickness * striking position) interaction of pattern (A), thickness (B), and striking position (C) has not reached the significance level (F=0.549, p>.05) in CT value performance before or after grinding. Therefore, the two-way interaction term is tested, and the simple main effect test is implemented if the interaction of various factors reaches significance. According to Table 5, the interactions of pattern (A) and striking position (C) (F=1.942, p<.05) and thickness (B) and striking position (C) (F=43.125, p<.05) have reached the significance level in CT value performance, thus, simple main effect analysis is implemented. Table 6 and Table 7 show the simple main effect analysis of CT value performance before and after grinding the striking face. Table 6 shows that seven of 10 simple main effects have reached the significance level. Table

7 shows that all of the five simple main effects have reached the significance level.

The statistical results of three-way analysis of the pattern, thickness, and striking position show that significant difference is not reached; while CT after grinding is enhanced, the effect is not significant. Two-way analysis shows that there is significant difference between the pattern and striking position, as well as between the thickness and striking position (Table 5). The results of the simple main effect and LSD posteriori comparison show that Pattern 7 has not reached significance in different striking positions; while in the striking faces of the other patterns, the center is better than the open striking position; Pattern 1 and Pattern 2 are better than the close striking position, meaning the close center striking position has the best spring performance (Table 6). Different patterns are analyzed according to striking position, and posteriori comparison shows that the center striking points of Pattern 1, Pattern 2, and Pattern 3 are significantly better than Pattern 4 to Pattern 7. As abovementioned, thickness is the key factor to influence CT value performance. Therefore, performances in different striking positions have reached significant difference. According to posteriori comparison, the center position is better than the open and close striking positions before grinding; while the center and close positions are better than the open striking point after grinding.

Table 6. Simple main effect test abstracts of back pattern and striking position in CT value.

Source of variation	SS	Df	MS	F value	Posteriori comparison
Pattern(A)					
Pattern 1	7824.111	2	3912.056	15.549*	C2>C1,C3
Pattern 2	6397.000	2	3198.500	15.267*	C2>C1,C3
Pattern 3	8535.111	2	4267.556	8.677*	C2>C1
Pattern 4	5061.444	2	2530.722	6.375*	C2>C1
Pattern 5	3748.111	2	1874.056	5.687*	C2>C1
Pattern 6	4441.000	2	2220.500	6.637*	C2>C1
Pattern 7	2492.333	2	1246.167	2.981	
Position(C)					
CT-open	323.667	6	53.944	0.708	
CT-center	3617.905	6	602.984	3.725*	A1>A4-A7; A2>A4-A7; A3>A4-A7
CT-close	941.810	6	156.968	0.122	

PS: *p<.05; C1 = CT-open, C2 = CT-center, C3 = CT-close

Table 7. Simple main effect test abstract of thickness and striking position in CT value.

Source of variation	SS	Df	MS	F value	Posteriori comparison
Thickness(B)					
Before grinding	17836.222	2	8918.111	80.955*	C1< C2 C3< C2
After grinding	30948.667	2	15474.333	64.284*	C1< C2 C1< C3
Position(C)					
CT-open	609.52381	1	609.524	10.236*	B1<B2
CT-center	2784.857	1	2784.857	17.140*	B1<B2
CT-close	33152.381	1	33152.381	102.253*	B1<B2

PS: *p<.05; C1 = CT-open, C2 = CT-center, C3 = CT-close

3) BOMBARDING TEST

After CT value testing of the club head, strike face striking and durability tests are implemented. The striking test, conducted by a club head bombarder, ensures the 455SS alloy selected in this study has enough strength to make a golf club head. When the club is tested by a club head bombarder, the club head is fixed and struck at 45m/s, the ball for the striking test is the Pinnacle Practice golf ball, and the striking points are center, open, and close. First, the Stage I striking test is implemented, where the club face is checked after the points on the club face are struck 1,000 times, and there is no crack or rupture. Stage II is the durability test, the club face status is checked after the points on the club face are struck 3,000 times, and there is no crack, rupture, or dent. The striking test continues till the club face dents, cracks, or breaks. In the durability test, club heads with various patterns are struck over 6,000 times, meaning the mechanical strength of the 455SS alloy for this club face design is applicable to the club face of a club head.

IV. DISCUSSION

This study analyzes the club faces of club heads made of 455SS alloy. A part of the thicknesses of the designed 7 patterns are milled off by a CNC milling machine on the back of the club face, which intends to develop a new generation of striking face products in nonuniform thickness. As this study uses practical production and testing for experimental analysis, the results are different from the simulated calculation and drawing software application research methods. Many errors and unknown variables are included by experimental control, thus, the results are the actual values of the club heads, and the reliability of the results is close to reality. Furthermore, as the research process is from club face design to club head production, the cost is high, and the supplier's cooperation is required for this step by step process; therefore, this method is seldom used in laboratory research, and there are few empirical references regarding this aspect, thus, this study only describes and discusses the obtained data.

A. MECHANICAL PROPERTIES AND MICROSTRUCTURE OF 455SS ALLOY MATERIAL

This study selects 455 stainless steel as the alloy material for club heads, which is heated at different temperatures to enhance the mechanical properties. The grain variation of the alloy material after the heating procedure is analyzed by SEM, which attempts to determine the optimum heat treatment temperature. The findings show that, water cooling after 30 minutes' solution treatment at 850℃ and water cooling after 4 hours' solution treatment at 550℃is optimal, as the grain size influences the mechanical properties of the alloy, meaning the fine-grained material is harder and stronger than coarse-grained material. Therefore, SEM analysis shows that the 455 stainless steel has the minimum grain size at S850℃-A550℃ (Table 2, Figures 3 to 7). The testing data obtained from extension, hardness, and density testing are confirmed (Table 2). Therefore, this study selects the 455 stainless steel material after the heating procedure at S850℃-A550℃ to make the club head.

B. CT PERFORMANCE OF CLUB HEAD STRIKING FACE

Over the past decade, the average driving distance of golfers has increased by about 20 yds. meaning when playing an old course, the players can easily master the preset obstacles. The increased driving distance represents a larger club angle and shorter length, thus, direction control and accuracy are enhanced during striking, and players can continuously break their performance and score records. However, this situation is not good for course or match sponsors, as recorded scores are continuously broken, it means court difficulty is lower and lower, reducing the fun and challenge of golf, and influencing the sustainable development of golf. Therefore, in 2004 and 2009, the USGA and R&A restricted driver spring effectiveness and updated the testing method, and hoped the players would pay attention to the training development of their technique and physical performance, instead of seeking breakthroughs brought by equipment. However, for equipment manufacturers, the key point is to increase profit, and make products that are accepted by golf fans to create good sales results. There is a contradiction between the competent authorities and equipment manufacturers, thus, equipment manufacturers change their product development strategies by considering profits; on one hand, they develop clubs that meet the specifications, on the other hand, they design clubs with high spring effectiveness for general golf amateurs, and especially for the elderly, in order that this group of fans can enjoy the sport and obtain a sense of achievement in optimum sports performance. Therefore, this study hopes to break through the existing equipment from the angle of equipment suppliers, in order to increase sales performance and profit. There are two reasons for selecting the fairway wood as the research subject. First, the limitation of spring effectiveness is not specified. Secondly, it has handiness and a low miss ratio, as compared with a driver. Therefore, if the performance of a fairway wood in driving distance approaches the driver, and there is very high accuracy and controllability, errors can be reduced and sports performance can be enhanced for users. For equipment manufacturers, the selling price can be increased to increase revenues, leading to win-win effects.

In order to obtain high CT value, there are two variables that influence CT in this work, one is the thickness, and the second is the mechanical strength of the alloy material. Under such preconditions, in order to determine the optimum CT value performance and avoid ruptured or cracked thin club faces, a part of the pattern on the club face backside is milled off to reduce the thickness and weight. The findings show the average CT values at three club face striking measurement points after 0.1mm grinding, the CT value performance of the different thicknesses is enhanced, and there is significant difference ($p<.05$), meaning the change in thickness is correlated to the increased CT value to some extent. This is coincident with Kuo and Chao [5] and Peng [4], when the material is Ti alloy or stainless steel, provided the relationship between mechanical strength and the thickness of alloy is mastered, CT performance can be enhanced. In terms of striking positions, the center and close striking positions have better performance than the open striking position, meaning that striking the close center has the optimum spring effectiveness. In terms of the 7 striking face patterns, the CT value performance after grinding is better than that before grinding; however, significant difference is not reached according to statistics, meaning the thickness can enhance the CT value performance, while the enhancement of CT value performance by different pattern designs is limited, or the partially milled thickness shall be increased. In comparison to the CT value performance of a striking face in the nonuniform thickness of the original design, which is about 220μs, striking faces with different patterns, as designed in this study, have better performance (238μs) than the original club head.

The results of strike resistance testing show that the 455 stainless steel material has high strength, and when made into a thin club face, the result still meets the standard. This is an additional option for club development, as stainless steel material is resistant to corrosion and rust, thus, appearance treatments can save extra expenditures.

V. CONCLUSION AND SUGGESTIONS

It is universally known that a change in thickness can effectively influence the CT value of a golf club face. While the overall thickness was reduced in the past, the mechanical strength of the alloy decreased with the thickness, and there were ruptures and cracks, leading to customer complaints. Therefore, this study uses CNC machining to partially reduce the thickness of the back of the club face. While the actual test results show that the CT value performance of spring effectiveness is enhanced, statistical analysis shows that the CT value performance of thickness and pattern has not reached significant difference, and the strike resistance test meets the specification, meaning reducing partial thickness reaches the club head specification; however, the results of enhancing spring effectiveness requires further studied. According to the overall actual numerical values, the maximum CT value is 257.6μs, and the CT value at different striking points is 261.3μs, which exceed the highest CT value specified by USGA, meaning the direction of this study is feasible. The sample number may be increased in the future studies, or ferrous material with higher strength can be selected. In terms of the designed back patterns, Pattern 2 and Pattern 3 have the best CT value performance, and future research can continue in this direction.

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