Analysis of the Hot Forging Process Parameters of CCM Alloy for Medical Device

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Abstract: Cobalt-chromium-molybdenum (CCM) alloy has been widely used in orthopedic implant materials due to its good mechanical properties, abrasion resistance and excellent corrosion resistance. Hot forging manufacturing process is the primary method for the forming of CCM alloy in current industry. To understanding the effect of preheat temperature of the hot forging process for CCM alloy on the materials property, we evaluated the preheat temperature range based on performance requirement of the orthopedic implant product, focus on the effect of forge preheat temperature upper/lower temperature limit to the mechanical property, hardness and microstructure. Through mechanical property testing, hardness testing and microstructure observation to analyze the effect of high/low temperature to Co-Cr-MO alloy, to find out the optimal preheat temperature for C0-Cr-Mo ally hot forge.
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1. Introduction

Due to the dramatically elevation of the health medical standard, human life span has been greatly extended. However the need of some human organs, and bone and joint has increased due to aging and needs to be replaced with artificial materials. To continue the existence of the live and better living quality, it is necessary to develop new biomaterials. Bio materials are synthetics materials and are used to replace some living tissues or directly contact living tissue to perform its functional. According to Advisory Board for Biomaterials, Clemson University (Clemson, 1974), the definition of biomaterials was defined as: A systematically and pharmacologically inert substance designed for implantation within or incorporation with living systems.

Orthopedics replacement materials are the most developed biomaterials and are widely used. Current metals used in orthopedics are: Titanium, Titanium alloy, Co-Cr-Mo (CCM) alloy, and stainless steel. Due to their bi-compatibility, high strength, corrosion resistance, and wear resistance properties, Titanium alloy and CCM are the most used orthopedics-replacement biomaterials. Forging and cutting are two major machining methods [1].

This study is a joint university and industry project, the cooperated company is a well-known medical orthopedic equipment company. The goal of this project is to, via the mechanical properties testing, hardness testing and microstructure observation, evaluate forging preheat parameters of CCM alloy bone handle, and analyze the effect of preheat temperature to CCM alloy mechanical properties to find out the optimized hot forged temperature setting.

2. Literature review

People have utilized the strength of metal to fix bone fracture as early as 18th century. However, due to the use of metal such as Fe, Au, Ag, and Pt, the infection was severe, until 1986 when Dr. J. Lister improved surgical sterilization technique. In 1912, Sherman improved the design made by Lane and suggested using Vanadium steel to replace stainless steel as bone plate and bone screw. In 1924, Zierold developed Co-Cr alloy with pharmacologically inert characteristic. Later, 302 /316 stainless steel was introduced to improved corrosion-resistance property. Tantalum (Ta) was introduced at 1939 as the implantation material. But, due to its low mechanical properties and machining ability, it was seldom used as orthopedic implanted materials. However, since Tantalum is a good bio-compatible metal, it is still used in neurological and plastic surgery. 316L stainless steel with better machining capability and corrosion resistance was developed at 1950s and are used widely as Dental restorative materials and orthopedic Implantation materials. Cobalt base alloy (Co-Cr-Mo and Co-Cr-Ni-Mo) has better wear resistance and corrosion resistance properties and is still used extensively [2~6].

Cobalt base alloy such as Co-Cr-Mo alloy is called Vitallium. Its classical composition is Co-30 Cr-6 and contains carbon 0.35%. Its corrosion resistivity is forty times higher than that of stainless steel (Fe-18Cr-12Ni-2), and has excellent anti-fatigue and wear resistivity properties. It is a good orthopedic alloy material. Cr and Mo can help to improve the strength and corrosion resistivity; Mo can also block the growth of crystal in crystallization process to improve the wear resistivity ability. However, high hardness makes the materials difficult to machine. Because Co-Cr-Mo alloys have very high hardness and strength, hot forge forming is the method used for shape formation instead of cold forged forming. In Lin's study [7], Co-Cr-Mo alloy has excellent corrosion and resistivity and bio-compatibility, therefore, a good orthopedic implantation material candidate. Dynamics forging test is performed to determine the proper deformation and deformation temperature.

In general, solution and/or heat treatment and aging process are conducted to enhance the mechanical properties of metal alloys and medical material [8][9][10][11], Ghi [12] used crank shaft as an example and use finite element method to simulate the effect of mold preheat temperature on the forming process. The results showed that mold preheat temperature has a great effect on the forming and mold wear.

3. Experiment process

Specimens used in this test were provided by corporate company. Preparation for the specimens included three forging process. They were preliminary bending, completing forging and shaping forging. Specimens were preheated before each forging process. Stem forging parts were sampled and performed tensile; hardness and Metallographic testing after shaping forging to evaluate the effect of upper/lower forged preheat temperature on the forged mechanical properties. Fig. 1 shows the stem forged manufacturing process.

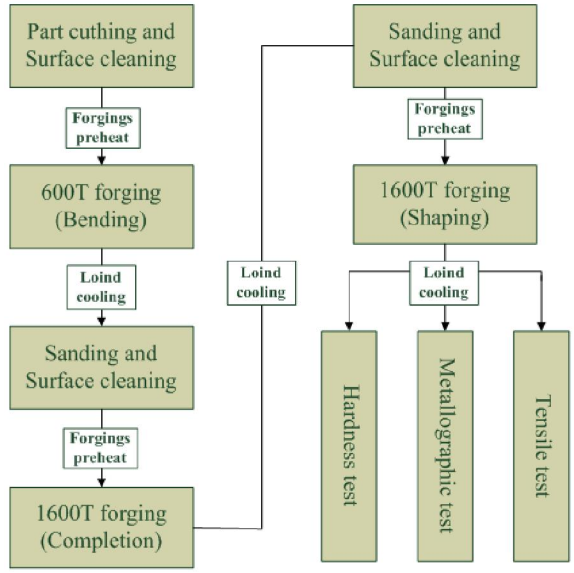


Fig. 1 Stem forging manufacturing process

Table 1 shows the forging parameters used in this study: Group A is the samples with upper preheat temperature limit; group B is the samples with lower preheat temperature limit.

Table 1. Co-Cr-Mo alloy forging parameters

group	Processing parameter setting	600T forging (bending)	1600T forging (completion)	1600T forging (shaping)
A	Furnace setting temperature (℃)	(A)	(A)	(A)
	Constant temperature duration after reaching setting temperature (min)	6 < t < 25	7 < t < 25	6 < t < 25
	Furnace temperature after sampling (℃)	(A)	(A)	(A)
	Time to complete forging process after sampling (s)	t < 10	t < 10	t < 10
B	Furnace setting temperature (℃)	(B)	(B)	(B)
	Constant temperature duration after reaching setting temperature (min)	6 < t < 25	7 < t < 25	6 < t < 25
	Furnace temperature after sampling (℃)	(B)	(B)	(B)
	Time to complete forging process after sampling (s)	10 < t < 15	10 < t < 15	10 < t < 15

Table 2. Tensile test results

Specimen No.	Yield stress (N/mm^2)	Tensile stress (N/mm^2)	Elongation (%)	Cross section compaction ratio(%)	Comment
A-1	1020.8	1300.6	10.43	15.27	
A-2	990.5	1290.0	11.45	13.71	
A-3	999.4	1283.1	11.60	14.54	
A-4	961.7	1270.7	11.08	13.09	
Mean	993.10	1286.10	11.14	14.15	
Standard derivation	21.21	10.86	0.45	0.83	
Specimen No.	Yield stress (N/mm^2)	Tensile stress (N/mm^2)	Elongation (%)	Cross section compaction ratio(%)	Comment
B-1	1126.0	1395.8	10.91	14.93	
B-2	1131.2	1399.7	11.63	16.34	
B-3	1103.4	1383.6	11.21	16.03	
B-4	1133.4	1398.7	11.51	15.67	
Mean	1123.50	1394.45	11.32	15.74	
Standard derivation	11.91	6.43	0.28	0.53	

4. Results and Discussion

4.1 Mechanical Properties

Mechanical property tests were done on CCM alloy artificial hip joint stem forgings. Four specimens on each of two sets of preheat temperature forgings were chosen to perform the tensile test. Test results should accord with the acceptable values. According to Table 2~4, the tensile test results show that mechanical properties for the same preheat processing parameters do not derivate a lot.

Table 3. Yield Stress Analysis

Yield Stress	
A	B
1020.8	1126.0
989.2	1130.4
999.4	1103.4
961.7	1133.4

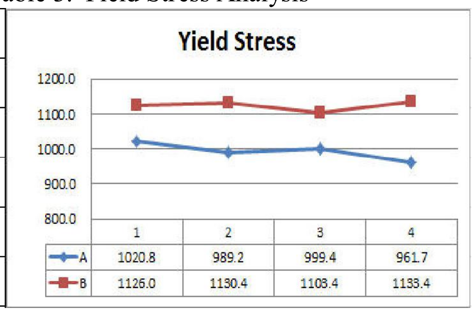
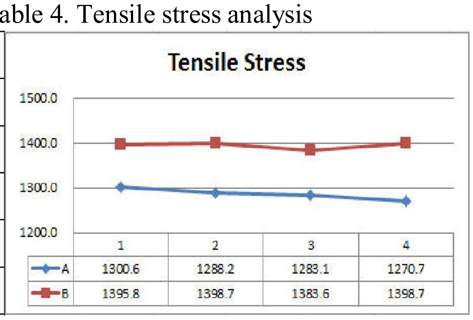


Table 4. Tensile stress analysis

Tensile Stress	
A	B
1300.6	1395.8
1288.2	1398.7
1283.1	1383.6
1270.7	1398.7



4.2 Vickers hardness analyses

One specimen from each group of CCM alloy artificial hip joint forgings was used for Vickers hardness test. Four different locations from each specimen were sampled for the test, as shown in Fig. 2. On each location, 9 points were chosen to do the tests; each sampling location is shown in Fig.3. Time duration for each point was 10 seconds and the load was 1kg.

Hardness test data and analysis results comparison are shown in Fig. 4 and Fig.5. From these figures, the hardness of both sides of the bone handle (points 1, 2,3,7,8, and 9) is smaller than that of the center points (points 4, 5 and 6). It is the resultant of forging process. Since the center of bone handle is the forging mold connected location, during the forging process, stress concentration causes concentrated crystal lattice that leads to high hardness.

4.3 Metallographic observation analysis

One specimen from each group of CCM alloy artificial hip joint forgings was used for Metallographic structure observation. Four different locations from each specimen were sampled for the test. On each location, 9 points were chosen to do the Metallographic observation analysis. Metallographic sampled locations and observation points are shown in Fig. 2 and Fig. 3.

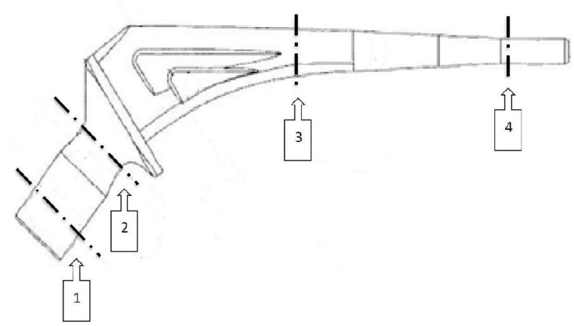


Fig. 2 Hardness test and Metallographic observation sampling locations

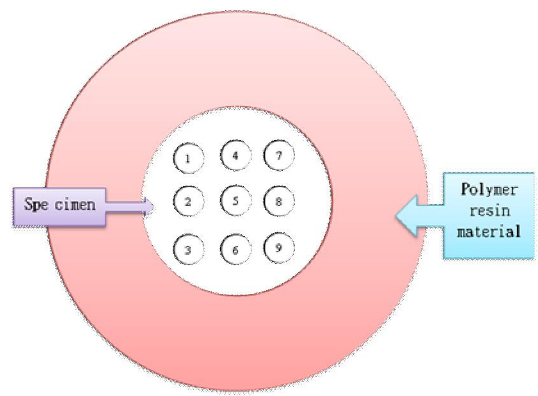


Fig. 3 Hardness and Metallographic testing point

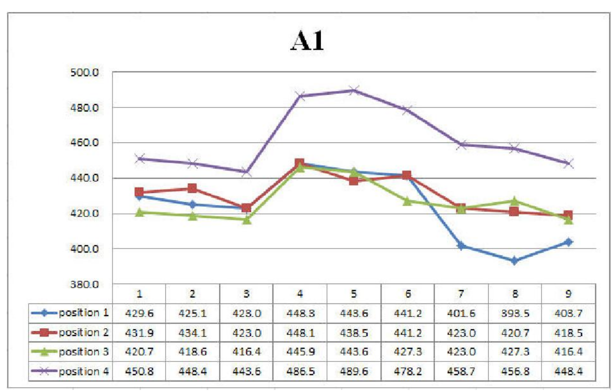
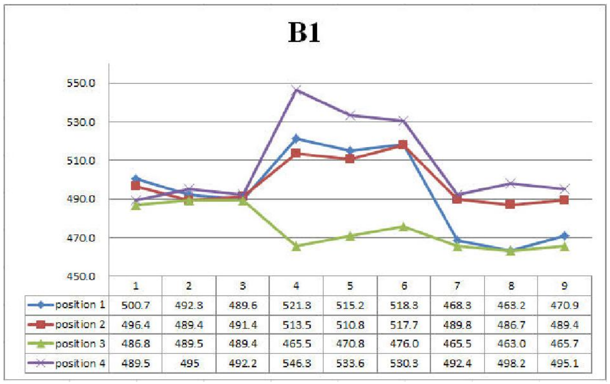


Fig. 4 CCM alloy Vickers hardness analyses (group A)



	1	2	3	4	5	6	7	8	9
position 1	500.7	492.3	489.6	521.3	515.2	518.3	468.3	463.2	470.9
position 2	496.4	489.4	491.4	513.5	510.8	517.7	489.8	486.7	489.4
position 3	486.8	489.5	489.4	465.5	470.8	476.0	465.5	463.0	465.7
position 4	489.5	495	492.2	546.3	533.6	530.3	492.4	498.2	495.1

Fig. 5 CCM alloy Vickers hardness analyses (group B)

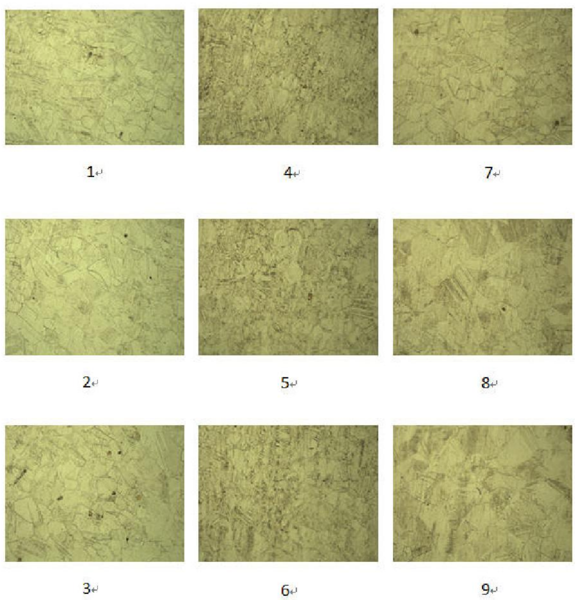


Fig. 6 Metallographic structure of the first sampled position of the specimen (group A)

Through the observation of the Metallographic structure results, it was discovered that both sides of crystal lattice (points 1, 2, 3, 7, 8, 9) is larger than that of central crystal lattice (points 4, 5 and 6). Central crystal lattice is much concentrated. Metallographic structure for 9 observation points for 1^{st} sampled point of groups A and B are shown in Fig. 6 and Fig.7.

5. Conclusions

Test results showed that the mechanical properties and hardness accord with ASTM F799 standard [17], the following are the conclusions:

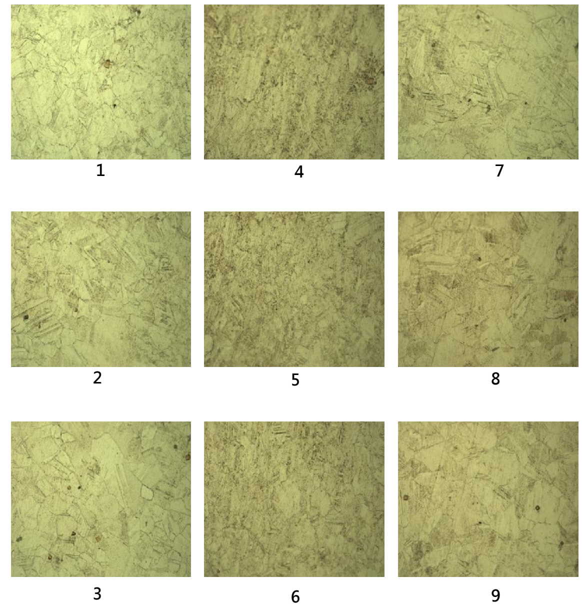


Fig. 7 Metallographic structure for each observation point (group B)

1. For those specimen with the same preheat hot forging parameters, the variation of mechanical properties is not large. This means that temperature control on the preheat process was good and the tests results are trustful.
2. Hardness test results shows that the specimen center has higher hardness than that of the other two sides. After the metallographic structure observation, central crystal lattice is smaller and much concentrated than that of the other two sides. This phenomenon is caused by forging process. Since homogenization heat treatment is not performed on CCM forgings, crystals on sides of the specimen grow into thick and large tree like structure. However, after homogenization heat treatment, inner tree like structure grains are recrystallized, and the grains are refined, this reduces the hardness, improves material toughness, and still maintains the mechanical properties.
3. According to mechanical properties and hardness test results, the variations of preheat temperature affects the CCM alloy forgings. Forgings with lower preheat temperature setting has higher mechanical properties and hardness. However, mechanical properties and hardness for forgings with higher preheat temperature setting are much closer to the standards. Upper limit preheat temperature setting is suitable for CCM alloy forging process.

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References

1. http://www.chinabaike.com/article/316/332/2007/20 07022046737.html.
2. Chueh Shan Chang, "Metallic bio material introduction," Chemical Technology, 2000.
3. Sullivan, C. P., Donachie, M. J., Jr., Morral, F. R., "Cobalt Based Superalloys. Brussels: Centre d'Information de Cobalt," 1970.
4. Merget, M., Aldinger, F., in: Titanium, Science and Technology; Lutjering, G., Zwicker, U., Bunk, W. (Eds.). Oberursel, F.R.G.; Deutsche Gesellschaft fur Metallkunde, 1985.
5. Zweymuller, K. A., Lintner, F. K., Semlitsch, M. F., Clinical Orthopaedics and Related Research, Vol. 235, 1988.
6. Cohen, J., Rose, R. M. and Wulff, J., Journal of Biomedical Materials Research, Vol. 12, 1978.
7. Lin Ying-ying, Tang Zhi-jin, and Lin Hai Xue Zhi-zhong, "Precision Forging Technology of CoCrMo Alloy," Journal of Aeronautical Materials, Beijing Institute of Aeronautial Materials, 2011.
8. El-Morsy A, Farahat A., "Microstructure Variation and Mechanical Behavior of Aged AZ61 Wrought Magnesium Alloy," Life Sci. J.; 10(3):568-574, 2013.
9. Manal R. Abu-Eittah, "Assessment of Different Surface Treatments Effect on Surface Roughness of Zirconia and Its Shear Bond Strength to Human Dentin," Life Sci. J.; 9(4):1792-1803, 2012.
10. Ola. M. Sakr, "Effect of Ulrra Short Pulse Laser on dentin structural changes and surface roughness," Life Sci. J.; 9(4):957-962, 2012.
11. Izadi Gonabadi H, "Physical and Mechanical Characteristics of Heat Treated P/M Parts, Infiltrated by Copper," Life Sci. J.; 10(6s):86-91, 2013.
12. Ji Jinjin, Zhou Jie, Yang Hai, Huang Liang, "Effect of Preheating Temperature of Hot Forging Die on Material Forming and Die Wear," Hot Working Technology, College of Materials Science and Engineering, Chongqing University, 2013.
13. K.S. Liu, S.G Lin, S.L Li, H.C Cheng and C-W Yeh, "Engineering Materials Science," One Tech Books Store, 1996.
14. Y. C. Chen, H. Y. Deng, "Mechanical Materials Testing," Kao Li Book Publisher, 1997.
15. K.S. Liu, S.G Lin, "Engineering Materials Science," One Tech Book Store, 2000.
16. C-S. Tsai, "Materials testing," Wun Chin Book Store, 2004.
17. ASTM F799-11, "Standard Specification for Cobalt- 28Chromium- 6Molybdenum Alloy Forgings for Surgical Implants," (UNS R31537, R31538, R31539).

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