Comparative study of bonang gamelan musical instrument between hot forging and Post Cast Heat Treatment/PCHT on microstructure and mechanical properties

S Slamet1,2, I Kusumaningtyas1, Suyitno1,3
1Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia
2Mechanical Engineering, Universitas Muria Kudus, Jl. Gondangmanis Po.Box 53, Bae Kudus, Indonesia
3Center for Innovation of Medical Equipments and Devices/CIMEDs, Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada, Indonesia
Corresponding author (E-mail): sugeng.slamet@umk.ac.id

Abstract: Metals have long been used to produce various musical instruments to date. Bonang Gamelan is one of the traditional musical instruments of Karawitan. Tin bronze was the primary choice because this alloy is capable of form and has excellent acoustic properties. This study aims to compare the forging technique with post cast / PCHT heat treatment at a temperature of 550 °C with changes in microstructure and mechanical properties of Cu-20wt.% Sn and Cu-22wt.%Sn. Characterization of mechanical properties includes hardness/VHN, tensile strength (σs), and bending (σb).

The forging and post-cast heat treatment/PCHT can improve the mechanical properties of hardness, tensile strength, and bending of the bonang gamelan product. The heat treatment process at 550 °C followed by holding time for 4 hours, followed by quench was able to produce grain growth and homogenization of the eutectic phase. The modulus of elasticity of the bonang gamelan specimen to the tensile strength was inversely proportional to the bending strength.

1. Introduction
Manufacture of metal products through the forging process is widely used by industry. Forging techniques are the oldest techniques known to man other than casting techniques. Forging techniques can be done in cold and hot conditions. Forging is usually carried out several times a process and stopped for relaxation of stress. When the forging process ends, there is the relaxation of stress on the metal along with the decrease in the forging force [1].

Hot forging is done by forging under the recrystallization temperature [2]. Recrystallization allows the formation of new grains in the metal. The advantage of the forging process is that it produces a high strain rate; the metal easily flows and allows the formation of recrystallization. The method of forging is formed in a plastic phase to create objects as desired [3]. Forging at low temperatures can improve dimensional control, reduce oxidation and low heating energy. Forging at low temperatures also increases residual stress rates, fatigue, and decreases mold life [4]. In addition to forming and heat treatment methods, increased hardness and material density can be improved by shot peening surface treatment methods [5][6].
Figure 1. The process of manufacturing gamelan in the home industry

The multi-directional forging technique of high lead-tin bronze alloy produces finer grain sizes, dislocations, increase the density, tensile strength, yield strength, hardness, ductility and reduce the rate of wear [7][8]. The process of forging at high temperatures in the β titanium alloy phase produces a rough Widmanstatten microstructure, decreasing tensile strength by forming brittle faults [9]. Forging techniques in Javanese gamelan, as shown in figure 1.

Tin bronze consists of high tin bronze ≥ 17% Sn and low tin bronze ≤ 17% [10][11]. Increased tin composition up to 10wt.%Sn on copper can increase tensile strength without embrittlement. Bronze with low tin content causes the product to be brittle. Bronze is widely used to produce various artifacts, pottery, and vessels thousands of years ago in Korea and China. High tin bronze is used to make multiple musical instruments such as gamelan, trumpet, gong and church bells [12][13]. Tin bronze has castability, flowability, formability, wear and corrosion resistant and also suitable strength. The addition of tin composition to copper alloys increases flowability [14]. Bonang gamelan manufacturing process by the sand casting method is shown in figure 2.

Figure 2. The cast bonang manufacturing stages (a) sand mold (b) mold ready to poured (c) pouring metal liquids (d) cast bonang products

The heat treatment of metals will have an impact on the mechanical properties, microstructure, and transformation of material phases. The heat treatment results in a free transformation of α + β phases in metal and sand molds. The α + β phase is more clearly seen in specimens with sand molds [15]. The
heat treatment followed by the aging process causes the degradation of particle solids, homogenization process, and an increase in the primary phase of eutectic Cu in Al-5,9Cu-1,9Mg alloy [16]. The treatment of annealing of Cu-6wt.%Sn alloys produced from rollers at 400 - 800 °C for 1 hour showed microstructure changes with crystal growth of up to 72.5% at 700 °C [17]. The tempering heat treatment of aluminum bronze results in a more homogeneous material structure. The mechanical properties of hardness and tensile strength have increased significantly. The formation of a new phase α + β is what causes hardness and toughness increased in the primary matrix [15]. The heat treatment followed by the aging process at high temperatures can smooth grain boundaries and cause increased hardness and toughness [18].

The purpose of this study is to investigate and compare changes in the microstructure of the mechanical properties of hardness, tensile strength and bending stress in cast gamelan products with some heat treatment and plastic deformation after casting (Post Cast Heat Treatment/PCHT). It is possible to produce gamelan by casting and improve mechanical properties by heat treatment.

2. Material and Method
The research material used Cu-20wt.%Sn Tin bronze alloys with sand casting method. The pouring temperature of metal liquid at 1100 °C. The composition of the tin bronze as shown in table 1.

| Materials | Cu | Sn | Fe | Bi | Pb | Zn | Mn | Ni   | Si   |
|-----------|----|----|----|----|----|----|----|------|------|
| Cu-22.1%Sn| 78,21 | 21,65 | 0,105 | 0,0013 | <0,005 | <0,003 | <0,0005 | <0,004 | <0,001 |
| Cu-20.0%Sn| 79,77 | 20,06 | 0,041 | <0,001 | 0,021 | 0,0813 | <0,0005 | <0,004 | <0,001 |

The mold sand material escapes mesh 150 to cover the inner surface and mesh 100 for the outer surface. The sand mold design, as shown in figure 3.

Test specimens consisted of 4 types including cast bonang with Cu-20wt.%Sn 1) no treatment (NT), 2) Heat treatment with temperature 550°C + holding time 4 hours + quench (HT), 3) Hot forging with a thickness reduction of 10% (HF). The above specimens were compared with bonang gamelan products from industries with Cu-22wt.%Sn produced by the forging method (HFT).

Observation of microstructure and investigation of mechanical properties including hardness, tensile strength, and bending obtained by cutting cast bonang and forged bonang method. The pieces of bonang gamelan instruments, as shown in figure 4.
Bonang specimens from cast products were then subjected to heat treatment at 550 °C and then held for 4 hours, followed by rapid cooling with water media. The specimen is cut transversely and longitudinally, then mounting and etching using a mixture of HNO$_3$ and H$_2$O. Microstructure observations were carried out at 100X magnification. Hardness testing uses the Hardness Vickers Number / VHN method with a load of 100 gr for 10 seconds. Tensile strength testing using ASTM E-8 and bending test ASTM E-290. The heat treatment and quench methods are shown in figure 5.

3. Result and Discussion

Observation of the microstructure of the cast bonang shows that the grain structure is relatively coarse and the deposition of $\alpha + \delta$ phases. The heat treatment process is 550 °C, holding time for 4 hours, followed by water cooling causes the degradation of $\alpha + \delta$ solid particles and increases the phase size of $\alpha$. The heat treatment process as such causes homogenization of the cast alloys [16]. The second phase changes from $\alpha + \delta$ to $\alpha + \gamma$ phase. The forging process causes the grain structure to change from round to elongated and flat. The microstructure of post-cast heat treatment / PCHT at a temperature of 550 °C followed by holding time for 4 hours and rapid cooling can reduce porosity, as well as microstructure of the forging process. The heat treatment and hot forging process show the recrystallization process. The microstructure of Cu(20-22)wt.%Sn for the different treatments, as shown in figure 6.
The mechanical properties of tin bronze with the casting method show a lower hardness value compared to other products, namely specimens with heat treatment of 550 °C held for 4 hours with water cooling and hot forging with a thickness reduction of up to 10%. Figure 7. shows the hardness of various bronze tin treatments on cross-sections figure 7(a) and longitudinal sections figure 7(b).

**Figure 6.** The microstructure (a) No treatment/NT (b) heat treatment 550 °C + holding time 4 hours + quench/HT (c) Hot forging with a reduction of 10%/HF (d) hot forging bonang for industrial products/HFT

**Figure 7.** Shows the hardness at the different treatment (a) cross-section (b) longitudinal section
The increased hardness and tensile strength of the forging product are strongly influenced by the microstructure formed and the chemical composition of the alloy. The Fe element in the alloy can increase hardness while the addition of a small amount of Pb can decrease the brittle nature.

Heat treatment and forging cause changes in the microstructure with an elongated and flat shape. Casting/NT followed by heat treatment, followed by holding temperature for 4 hours can increase elongation compared to other treatments. Increased elongation causes mechanical properties to increase ductility. Tensile strength and elongation of bonang product specimens at different treatments are shown in figure 8(a) and figure 8(b). The forged bonang gamelan specimens show greater tensile strength, but there is a decrease in ductility due to increased dislocation. The compared to bonang gamelan specimens by casting method and forging gamelan home industry products mechanical properties such as bending and tensile strength increase with heat treatment. The mechanical properties of gamelan specimens for bending stress and modulus show linearity. Hot forging followed by PCHT can improve the mechanical properties of gamelan bonang products. Hot forging can increase hardness, density and reduce porosity higher than HPDC [19]. Figure 9(a) shows the bending stress ($\sigma_b$) and figure 9(b) modulus of elasticity on the difference of treatment.

**Figure 8.** The mechanical properties at the different treatment (a) UTS  (b) Elongation
Microstructures with small grains tend to slip easily compared to flat grains [20]. Increased tin composition and pouring temperature increase the α phase grains and trigger the formation of columnar dendrites [21]. The process of plastic deformation through the process of rolling and forging causes the material to be anisotropic. The different grain directions and orientation will give different shapes and mechanical properties. The forging process causes the formation of non-uniform structures during cooling [2].

4. Conclusions
It can be concluded that the forging and heat treatment process after casting / PCHT can improve the mechanical properties of hardness, tensile strength, and bending of the bonang gamelan product. The heat treatment process at 550 °C followed by holding time for 4 hours, followed by rapid cooling can produce grain growth and homogenization of the eutectic phase. The modulus of elasticity of the bonang gamelan specimen to the tensile strength is inversely proportional to the bending strength. This shows that the application of the forging and PCHT method is suitable for producing gamelan without reducing ductility.

5. References
[1] I. G. Zhbankov, A. V. Perig, and L. I. Aliieva, “Calculation of recovery plasticity in multistage hot forging under isothermal conditions,” Springerplus, vol. 5, no. 1, 2016.
[2] M. G. Rathi and N. A. Jakhade, “An Overview of Forging Processes with Their Defects,” Int. J. Sci. Res. Publ., vol. 4, no. 1, pp. 2250–3153, 2014.
[3] S. Gebremeskel and R. Uppala, “Effect of Hot Forging on Chemical Composition and Metallographic Structure of Steel Alloys,” Glob. J. Res. Eng. Mech. Mech. Eng., vol. 12, no. 4, pp. 33–42, 2012.
[4] R. Arreola-Herrera, A. Cruz-Ramírez, M. Á. Suárez-Rosales, and R. G. Sánchez-Álvarado, “The effect of cold forming on structure and properties of 32 CDV 13 Steel by radial forging process,” Mater. Res., vol. 17, no. 2, pp. 445–450, 2014.
[5] V. Malau, B. H. Priyambodo, P. T. Iswanto, T. Sujitno, and Suprapto, “Increased hardness, corrosion resistant and corrosion fatigue cracking performance on AISI 304 by DC sputtering,”
Int. Rev. Mech. Eng., vol. 12, no. 12, pp. 975–980, 2018.

[6] B. H. Priyambodo, V. Malau, P. T. Iswanto, L. D. Setyana, S. Slamet, and Y. Kurniawan, “Improve corrosion resistant and corrosion fatigue cracking performance on AISI 304 by shot peening process as alternative biomaterials,” J. Corros. Sci. Eng., vol. 22, 2019.

[7] R. Gupta, S. K. Panthi, and S. Srivastava, “Study of Microstructure, Mechanical Properties and Wear Rate of High Leded Tin Bronze after Multidirectional Forging,” in Materials Today: Proceedings, 2015, vol. 2, no. 4–5, pp. 1136–1142.

[8] R. Gupta, S. Srivastava, N. K. Kumar, and S. K. Panthi, “High leded tin bronze processing during multi-directional forging: Effect on microstructure and mechanical properties,” Mater. Sci. Eng. A, vol. 654, pp. 282–291, 2016.

[9] D. M. Huang, H. L. Wang, X. Chen, Y. Chen, and H. Guo, “Influence of forging process on microstructure and mechanical properties of large section Ti-6.5Al-1Mo-1V-2Zr alloy bars,” Trans. Nonferrous Met. Soc. China (English Ed.), vol. 23, no. 8, pp. 2276–2282, 2013.

[10] Z. Tasliieukur, G. S. Altug, Ş. Polat, H. Atapek, and E. Turedi, “A Microstructural Study on CuSn10 Bronze Produced by Sand and Investment Casting Techniques,” Met. 2012, vol. 5, pp. 23–25, 2012.

[11] S. Srinivasan, “Indian High-Tin Bronzes and the Grecian and Persian World,” Indian J. Hist. Sci., vol. 51, no. 4, 2016.

[12] Sorrell and Lindsay, “INTRODUCE TO JAVANESE GAMELAN,” vol. 451, no. 1992, pp. 1–28, 2002.

[13] V. Debut, M. Carvalho, E. Figueiredo, J. Antunes, and R. Silva, “The sound of bronze: Virtual resurrection of a broken medieval bell,” J. Cult. Herit., vol. 19, pp. 544–554, 2016.

[14] S. Slamet, S. Suyitno, and I. Kusumaningtyas, “Effect of Composition and Pouring Temperatur of Cu- Sn on Fluidity, Density and Mechanical Properties by Investment Casting,” in ICCSET Universitas Muria Kudus, 2019, pp. 718–725.

[15] M. Kaplan and A. K. Yildiz, “The effects of production methods on the microstructures and mechanical properties of an aluminum bronze,” Mater. Lett., vol. 57, no. 28, pp. 4402–4411, 2003.

[16] H. Akhyar, P. T. Iswanto, and V. Malau, “Non treatment, t4 and t6 on tensile strength of al-5.9cu-1.9mg alloy investigated by variation of casting temperature,” in Materials Science Forum, 2018, vol. 929 MSF, pp. 56–62.

[17] W. Huang, L. Chai, Z. Li, X. Yang, N. Guo, and B. Song, “Evolution of microstructure and grain boundary character distribution of a tin bronze annealed at different temperatures,” Mater. Charact., vol. 114, pp. 204–210, 2016.

[18] J. Liu et al., “Microstructure evolution, grain morphology variation and mechanical property change of Cu-Sn intermetallic joints subjected to high-temperature aging,” Mater. Charact., vol. 135, pp. 238–244, 2018.

[19] Q. S. Slamet, “Karakterisasi Bilah Gamelan Berbahan Kuningan Cu22Zn melalui Proses HPDC dan Hot Forging,” J. Metal. dan Mater. Indones., vol. 2, pp. 2654–4962, 2019.

[20] D. Callister, “Material Science and Engineering,” Advanced Materials Research, vol. 462. pp. 188–190, 2007.

[21] S. Slamet, S. Suyitno, and I. Kusumaningtyas, “Effect of Composition and Pouring Temperatur of Cu- Sn on Fluidity, Density and Mechanical Properties by Investment Casting,” IOP Conf. Ser. Mater. Sci. Eng., vol. 547, pp. 1–7, 2019.

Acknowledgments
The author would like to thank the Ministry of Finance of the Republic of Indonesia through the assistance of research funding for the BUDI-DN scholarship program No. PRJ-6851 /LPDP.3/2016 and KUBE Sampurna Tunas Muda in the Godean Sleman—Yogyakarta.