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WARM FORMING OF IRON POWDER WITH AND WITHOUT ADMIXED LUBRICANT

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ABSTRACT

This paper reports the outcomes of a comparative study between warm forming of metal powder with and without using admixed lubricant. A lab-scale warm forming rig was designed and fabricated which enabled the generation of green compacts at elevated temperature. The feedstock from iron powder ASC 100.29 was prepared by mechanically mixing the powder with 0.4 wt% and 0.8 wt% of zinc stearate for 10, 30, and 60 minutes in the case of warm forming with lubricant. For the case of forming without lubricant, only iron powder ASC 100.29 was used as feedstock. The prepared feedstock was formed by varying the temperature from 30ºC to 200ºC to generate green compacts for the purpose of mechanical testing and microstructure evaluation. The results revealed that the properties of green compacts are affected by the existence of admixed lubricant as well as forming temperature. Green compacts having high strength and more homogenous grain distributions were obtained by using admixed lubricant.

Keywords: admixed lubrication; metal powder; mechanical properties; microstructure; warm forming;

INTRODUCTION

Uniaxial die compaction of metal powder in between ambient and the recrystallization temperature of the main powder constituent or better recognized as warm forming which is initiated in order to increase the mechanical properties and microstructure of engineering components [1-5]. This method can produce near-net shape or net shape high strength yet defect free components for a variety of applications [6-7]. There are five basic process steps required in order to generate a defect-free green compact through warm forming route, i.e., (i) feedstock preparation, (ii) filling of die cavity by powder mass, (iii) heating of powder mass and die assembly, (iv) compaction of the powder mass by axial punch, and (v) ejection of the green compact from the die cavity. During the compaction step, powder mass inside the die receives a large amount of axial pressure hence a considerable amount of friction force is generated during this period. The resulting density of the green compact is a strong function of the quality of the powder mass as well the forming parameters [8]. Sometimes, the green compacts

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are found to be cracked mainly due to the density gradient resulted from the inhomogeneous density distribution which might be due to the interparticle and die-wall frictions [9].

Considerable efforts have been devoted in studying the compaction stage during the cold compaction process [10-12], however there has been little detailed works are found on the warm compaction process with the exception of recent studies found in [13-16]. Many researchers [17-28] have conducted works in finding the suitable lubrication mechanism for compaction of metal powder in generating high quality mechanical components. However, less information is found on the effects of the percentage of lubricant content and mixing time to the mechanical properties and microstructures of green compacts formed at above ambient temperature. Therefore, the objective of this paper is to present the outcomes of a comparative study of iron powder forming at above ambient temperature with and without admixed lubricant.

EXPERIMENTAL DETAILS

A lab-scale warm compaction tool was designed and manufactured (Figure 1) which enabled the generation of cylindrical shape green compacts (Figure 2). Iron powder ASC 100.29 was used as main powder constituent during the experiment. This type of powder is normally used in most of the powder compaction industries. The as received powder has the particle size range of 20-180 μm. The powder manufactured by Höganäs AB Company has the composition of 1.5% Cu, 0.5% Mo, and 4% Ni balanced with Fe.

A series of warm compaction experiment was conducted using simultaneous multi axial compaction mechanism. Four point heaters (50 Watt each) were attached to the cylindrical shape die. The forming temperature was ranged from 30°C to 200°C while the compaction load was ranged from 60 kN to 130 kN. The generated green compacts were tested for their mechanical properties and microstructures in order to evaluate the influences of the forming parameters.

Mechanical properties were analyzed through density measurement, and three-point bending test (ASTM E290-09). Fill density was obtained by dividing the mass of the powder required to fully fill the die cavity by the volume of the die cavity. Green density was measured by dividing the mass of the green compact by the volume of the green compact.

The bending strength of each compact was measured through the Instron Universal Testing machine. The compact was hold tightly at both ends when a transverse force is applied at the middle of the compact. All data such as elongation, maximum stress and maximum strength were collected through the data acquisition system in the computer until the compact fractured or broke down. Scanning Electron Microscopy (Quanta 400, Serial Number 4022 262 32071, Manufactured by Fei) was used for observing the iron powder particle arrangements.

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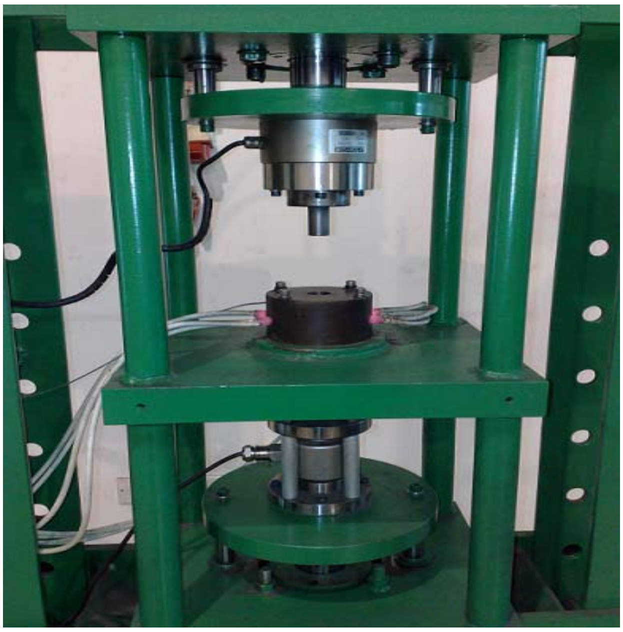

Figure 1: Warm compaction rig with complete heating system

Figure 2: Cylindrical shape green compacts

RESULTS AND DISCUSSIONS

During the densification process of powder mass, normal load acted on the powder mass resulted in powder displaced from its initial position. The deformation of the powder mass increased the relative density of the powder compact. As shown in Figure 3, the relative density of the green compact increases as the load increases. It is clearly evident that the addition of lubricant increases the density of green compact. Powder

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particles with higher lubricant content have higher mobility hence could easily occupy the void space left by the neighboring particles compared to powder mass without admixed lubricant. Therefore, lubricant content increases, the density of green compact also increases. Higher compaction load also contributed more uniform particle distribution inside the green compacts (Figures 4 and 5). More close packing order of iron particle with less macro and interconnected pores is observed at 130 kN compaction load.

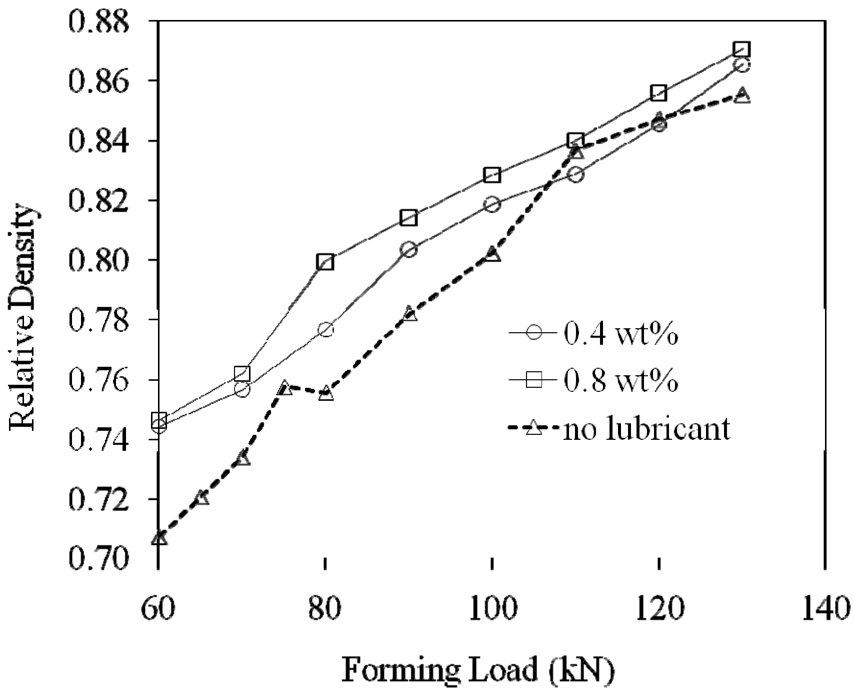

Figure 3: Relative densities of green compacts

Green strength of powder compacts are usually the result of cold welding process where the metal to metal bonding exists due to the compaction force exerted upon the powder mass. Therefore, it is evident in Figure 6 that admixed lubricant promotes the mechanical bonding even at very low compaction pressure as compared to the one without lubricant. This phenomenon also confirms the efficacy of the usages of zinc stearate as admixed lubricant. This result also indicated that the zinc stearate is forced out from the powder mass during densification process as the bending strength shows the mechanical bonding increment which reflects the minimal disturbance of zinc stearate inside the green compacts.

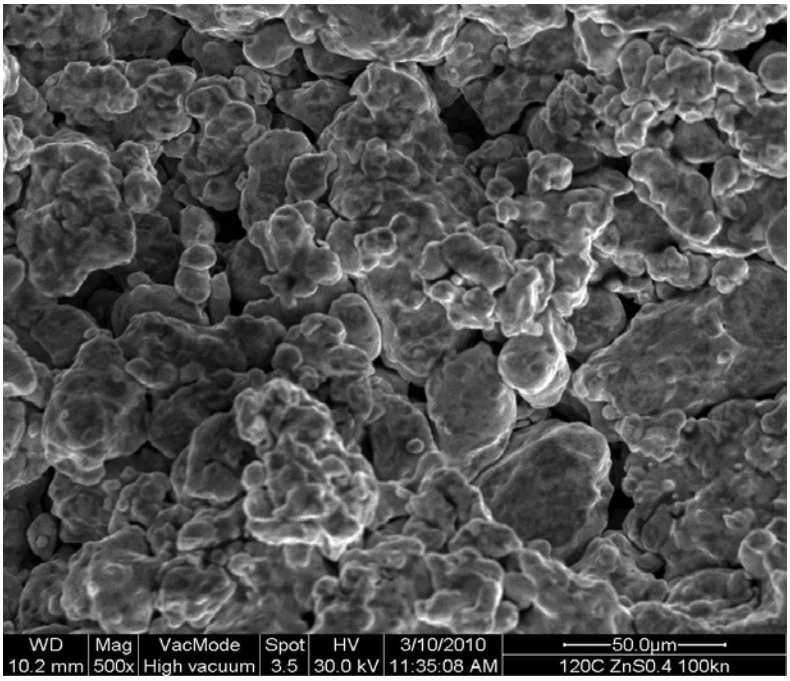

Figure 4: SEM image of green compact formed at 120ºC (0.4wt% lubricant)

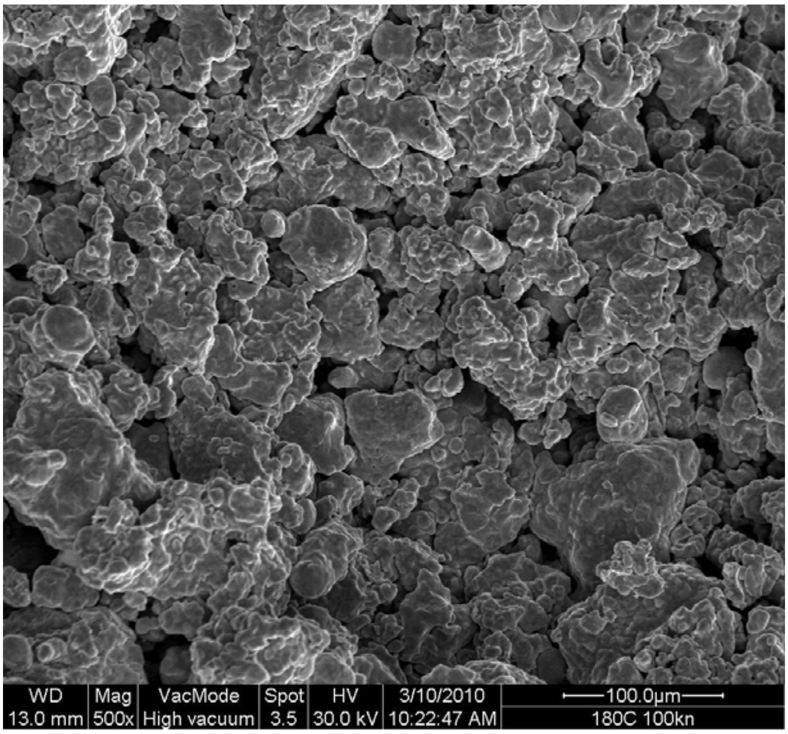

Figure 5: SEM image of green compact formed at 120ºC (0.4wt% lubricant)

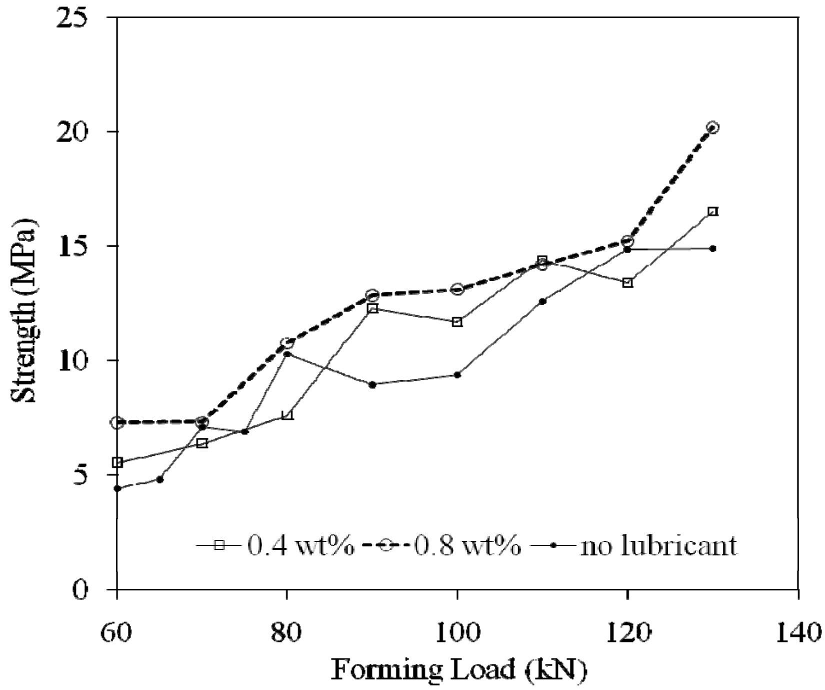

Figure 6: Bending Strengths of Green Compacts

Figure 7 shows the green density of iron powder without admixed lubricant formed at different temperature. It is evident that higher green density can be obtained by forming iron powder without admixed at 180°C because above this temperature, cold working as well as cold welding has been offset with the effect of thermal expansion of the iron atoms that produced larger iron particle in the powder mass. Therefore, due to this finding, iron powder with admixed lubricant has been tested by forming the powder mass up to only 180ºC.

Figure 8 shows that the relative density of powder mass without the lubricant increases as the forming temperature increases. However, the powder mass with admixed lubricant resulted less green density for the forming at 180ºC although both formulation, i.e., 0.4wt% and 0.8wt%, contributed better green density than without admixed lubricant. However, as can be seen in Figure 9, the green strength is higher in the compact with admixed lubricant rather than without lubricant.

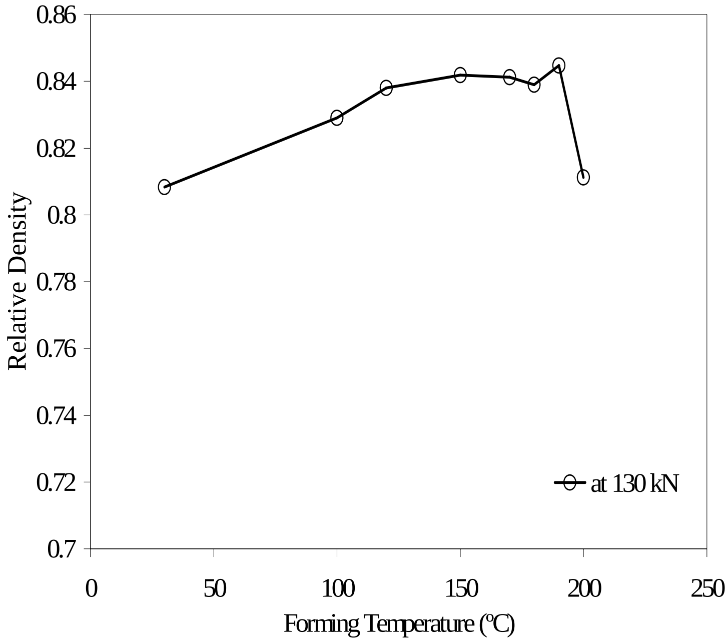

Figure 7: Relative densities at different forming temperature without lubricant

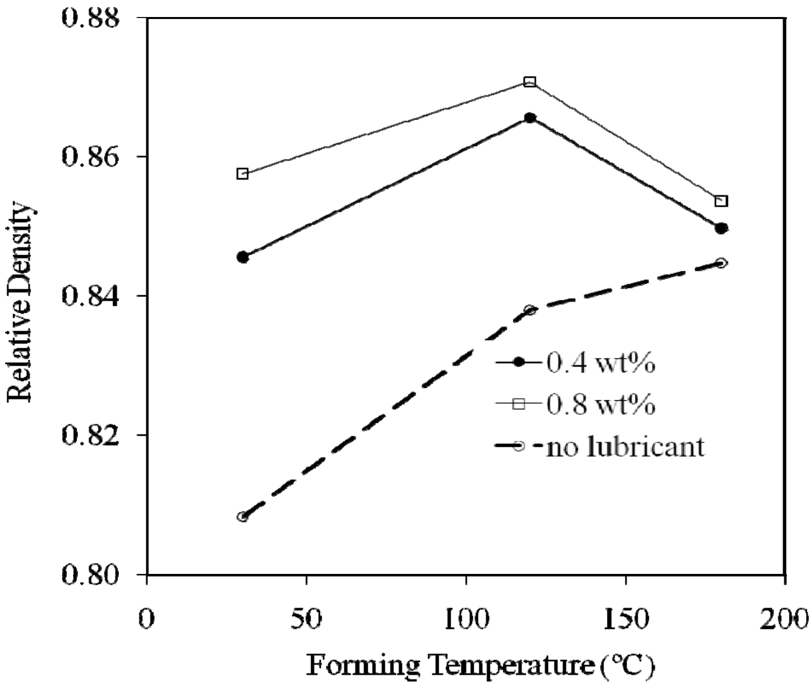

Figure 8: Relative densities at different forming temperature and lubricant

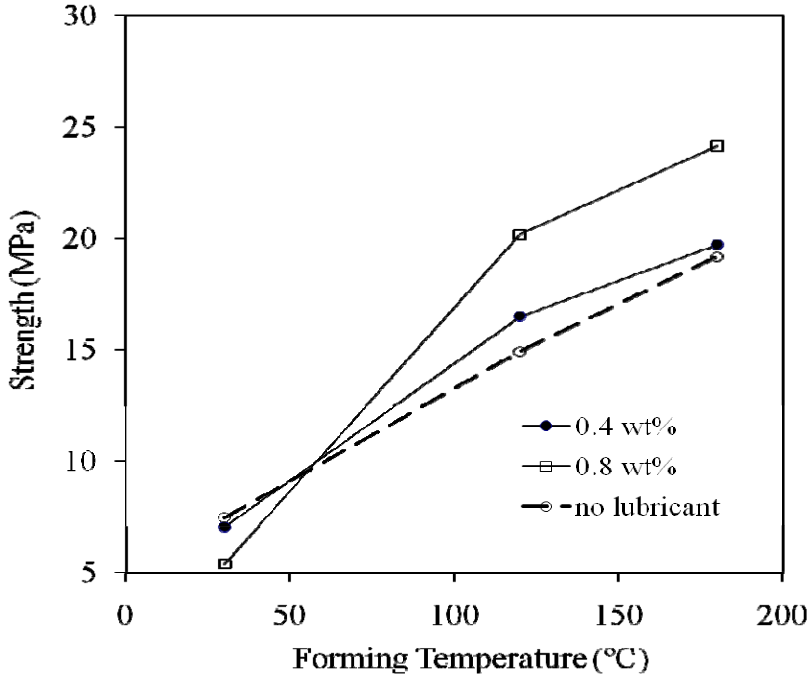

Figure 9: Green strengths at different forming temperature and lubricant

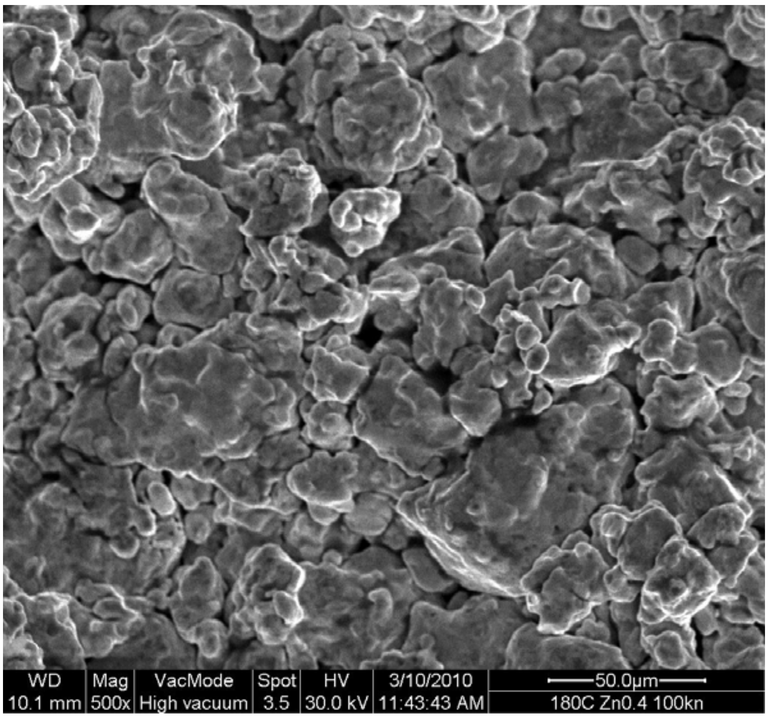

Figure 10: SEM image of green compact formed at 180ºC (0.4wt% lubricant)

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The difference in density and strength shows that forming load gives an excellent medium for the iron-zinc stearate movement while higher temperature gives good condition for the iron particle to interact among them, i.e., cold working. These combinations of load and temperature to the powder mass with admixed lubricant have produced higher green strength yet lighter in weight compared to the one without lubricant due to the proper arrangement of iron particles inside the green compacts (Figures 10 and 11). It also can be stated that at this compaction stage, higher amount of lubricant could increase the strength of green compacts

Figure 12 shows that mixing time also has significant effect to the green strength where the suitable mixing time is found to be 30 minutes. At that duration of mixing time, the powder particles were fully assimilated with zinc stearate hence enhanced the densification process [24]. However, longer mixing time, i.e, 60 minutes, could give adverse effect to the green strength. When a metal powder is mechanically mixed with a low density polymeric lubricant for a longer duration of time, granulation of powder particles with the lubricant is occurred which hindered the densification of powder mass hence the green compacts become less strong.

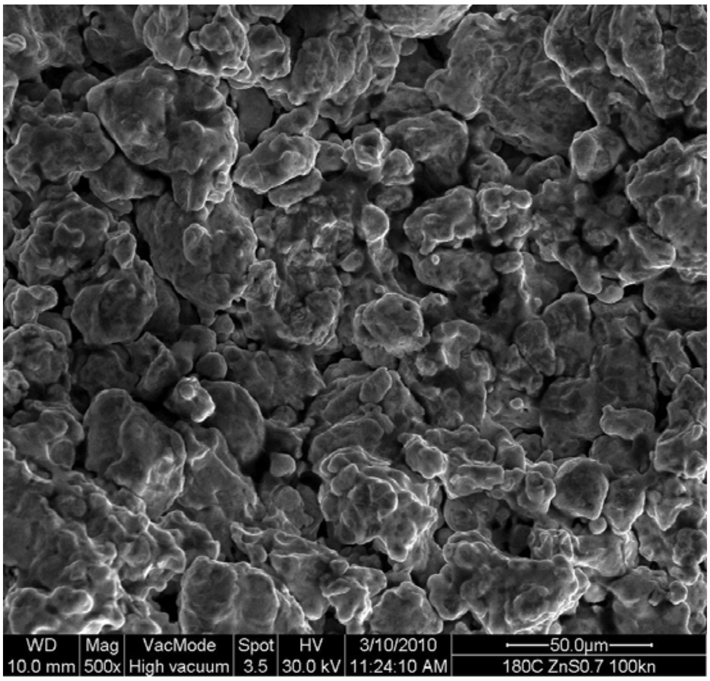

Figure 11: SEM image of green compact formed at 180ºC (0.8wt% lubricant)

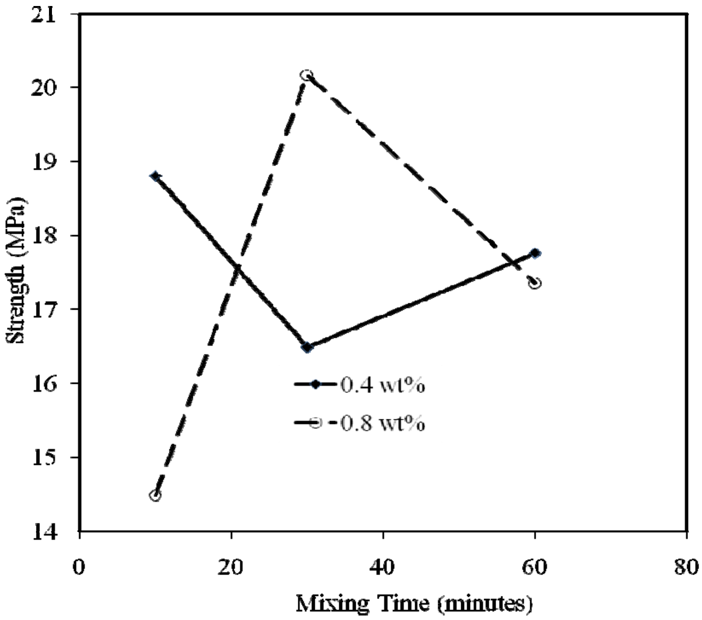

Figure 12: Flexure strength of green compacts for different mixing time

CONCLUSION

In order to justify the efficacy of zinc stearate as admixed lubricant during the formation of iron powder at above ambient temperature, a series of compaction experiment was conducted. The mechanical properties of green compacts were examined through density and bending strength measurement whereas the microstructures were evaluated through Scanning Electron Microscopy. The results revealed that admixed lubricant could contribute enhanced green properties, i.e., density, strength, and particle distribution.

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REFERENCES

[1] H.G. Rutz, F.G. Hanejko, (Advances in Powder Metallurgy & Particulate Materials, (Metal Powder Industries Federation, Princeton, NJ 1994)

[2] A.K. Ariffin and M.M. Rahman, *Journal of the Institute of Materials Malaysia.* **1** (2003) 161-174

[3] M.M. Rahman, A.K. Ariffin and S.S.M. Nor, Powder Metallurgy 2006 (PM'2006), Busan, Korea, September 2006, pp. 109-113

[4] M.M. Rahman, F. Tarlochan, S. Ramesh, A.K. Ariffin, S.S.M. Nor and M.R. Jamli, International Conference on Recent Advances in Mechanical & Materials Engineering (ICRAMME 2005), Kuala Lumpur, Malaysia, 30-31 May 2005

[5] S.S.M. Nor, M.M. Rahman, F. Tarlochan, B. Shahida and A.K. Ariffin, *Journal of Materials Processing Technology*. **207** (2008) 118-124

[6] M.M. Rahman and S.S.M. Nor, Malaysian Symposium on Advances in Powder Metallurgy and Particulate Materials (APM^2 07), Universiti Teknologi MARA (UiTM), Shah Alam, 21 - 22 August 2007

[7] J.Z. Wang, X.H. Qu, H.Q. Yin, M.J. Yi and X.J. Yuan, *Powder Technology*. **192** (2009) 131-136

[8] M.M. Rahman, A.K. Ariffin, S.S.M. Nor and H.Y. Rahman, *Materials and Design*. **32** (2011) 264-271

[9] Y. Kanno, J.A.C. Martins and A.P. Costa, International Journal for Numerical Methods in Engineering. **65** (2006) 62-83

[10] D.T. Gethin,V.D. Tran, R.W. Lewis and A.K. Ariffin, *The International Journal of Powder Metallurgy*. **30** (1994) 385-398

[11] E. Pavier and P. Doremus, *Powder Metallurgy*. **42** (1999) 345-352

[12] O. Coube, A.C.F. Cocks and C.-Y. Wu, *Powder Metallurgy*. **48**(2005) 68-76

[13] W. Bier, M.P. Dariel, N. Frage, S. Hartmann and O. Michailov, *International Journal of Mechanical Sciences*. **49** (2007) 766-777

[14] G.F. Bocchini, *Powder Metallurgy*. **42** (1999) 171-180

[15] M.M. Rahman, A.K. Ariffin and A. Anuar, The 2nd World Engineering Congress-Manufacturing Engineering, Automation & Robotics, Kuching, Malaysia, 22-25 July 2002

[16] M.M. Rahman, S.S.M. Nor and H.Y. Rahman, World Engineering Congress, Kuching, Sarawak, Malaysia, 2 - 5 August, 2010

[17] H. Rutz, J. Khanuja and S. Kassam, PM^{2}TEC '96 World Congress, Washington D.C., 16-21 June, 1996

[18] M. Ward and J.C. Billington, *International Journal of Powder Metallurgy*. **4** (1979) 201-208.

[19] W.J. Ullrich, K. Patel, R. Gotham and J.V. Marino, *International Journal Powder Metallurgy*. **30** (1994) 109-116

[20] H.G. Rutz, F.G. Hanejko, U. Engström, B. Johansson, Advances in Powder Metallurgy & Particulate Materials, (Metal Powder Industries Federation, Princeton, NJ, 1995)

[21] H.L. Sydney, Y.C. Frank, B.D. Alan and F.M. Thomas, International Conference on Powder Metallurgy & Particulate Materials, Chicago, USA, 29 June - 2 July 1997

[22] S. Turenne, C. Godere, Y. Thomas and P.E. Mongeon, *International Journal of Powder Metallurgy*. **42** (1999) 263-268

[23] M. Kondoh, Advances in Powder Metallurgy and Particulate Materials, (Metal Powder Industries Federation, Princeton, NJ, 2002)

[24] M.M. Rahman, F. Tarlochan, S. Ramesh, A.K. Ariffin and S.S.M. Nor, *Key Engineering Materials*. **462-463** (2010) 704 - 709