International Journal of Mechanical
Engineering (IJME)
ISSN(P): 2319-2240; ISSN(E): 2319-2259
Vol. 3, Issue 2, Mar 2014, 11-16
© IASET

International Academy of Science, Engineering and Technology
IASET
Connecting Researchers; Nurturing Innovations

INVESTIGATING THE EFFECT OF THERMO-MECHANICAL TREATMENT ON TOUGHNESS AND MACROSCOPIC WORK-HARDENING RATE OF LEAD ALLOY

DATAU, S. G,[1] DATAU NICODEMUS,[2] ANBUA, E. E[3] & BISU, D. Y[4]

[1,3,4]Department of Mechanical Engineering Technology, Federal Polytechnic, Bauchi, Nigeria

[2]Mechanical Engineering Programme, ATBU, Bauchi, Nigeria

ABSTRACT

The effect of deformation, deformation rate and temperature on the toughness and macroscopic work-hardening rate of a recycled lead alloy part whose chemical composition is shown in table 1 was investigated in the temperature range of room temperature to 200^{o}C, and in the deformation rate range of 0.3s^{-1} to 2.3s^{-1}. A high-low-temperature thermo-mechanical treatment technique was employed for this study. Lead alloy from waste batteries of cars were recycled into simple cylindrical parts by means of sand casting. The specimens were then heated to the required temperatures and then quenched in water before subjecting it to deformation. Deformation process was carried using an extruder at the Makeri Smelting Company in Jos. The toughness increased when the deformation, deformation rate and temperature were increased. A deformation of 99.5% at temperature of 150^{o}C and at deformation rate of 1.9s^{-1} resulted in a toughness of 16.94MN/m^2. Also, macroscopic work hardening rate increased with increased in deformation.

KEYWORDS: Thermo, Mechanical Treatment, Toughness, Mascropic, Work-Hardening Rate, Deformation, Deformation Rate and Temperature

INTRODUCTION

Non-ferrous metals and alloys form an important group of materials of industrial importance. Lead and its alloys fall in this group of these significant non-ferrous metals and alloys. Some commonly used lead alloys are solder, bronze, pewter, lead calcium babbit, etc. Lead alloys are commonly used for production of bearings, roofing sheets, pipe on telephone cable, battery plates and table ware (Laktin, 1986 and Rajan et al, 1988).

However, one of the main problems with which physical metallurgy is concerned is how the structures of metals and alloys are related to their mechanical properties such as tensile strength, hardness, toughness, etc (Benjamin et al, 1976 and Sircar,1996). Mechanical properties of metals are structure-sensitive, in the sense that they depend upon the type of crystal structure and its bonding forces and especially upon the nature and behaviour of the imperfections that exist within the crystal itself or at the grain boundaries (Jatau et al, 1999 and Askeland, 1925). To predict the behaviour of a material under load, engineers require reliable data on the mechanical properties of materials. In design, the most frequently needed data are tensile and yield strength, hardness, modules of elasticity and handbook on data is available for the average properties of common of alloys at 5.8^{o}C (Askeland, 1925; Mabuchi et al,1996; and Jastrebski, 1987). In practice, lead alloys are constantly subjected to failure such as cracks (Liu et al, 1991 and Lakin, 1986). To date, the effect of deformation, deformation rate and temperature on the yield and ultimate strength and uniform elongation has been investigated. It is established that the mentioned mechanical properties increased with increase in deformation, deformation rate and temperature up to 99.5%, 1.9s^{-1}, 150^{o}C respectively (Jatau and Datau, 2002). This work studies the influence of deformation; deformation rate and temperature on toughness and macroscopic work-hardening rate of lead alloy to ascertain its use as structural component in service where it constantly subjected to twist, repeated loading. high temperature performance e.g. shafts, spring, gasket, etc.

MATERIALS AND METHOD

Materials/Equipments

Lead alloy scraps (sourced locally from waste vehicle batteries); Crucible container; open- hearth furnace; charcoal; compressed air; a temperature probe, copper element, chemical composition analyzer, cylindrical pipe, lathe machine, venier calliper and extruder.

Method

The lead alloy scrap was sourced locally from waste batteries of vehicles. It was prepared and arranged in a crucible which was then placed in the open-hearth furnace for melting. The open-heart furnace was lighted and compressed air was used to blow the charcoal. Care was taken to ensure that melting temperature was attained and a temperature probe was used to ascertain this. When the scrap of the lead alloy was fully melted to its molten state, it was poured into the already prepared mould, cylindrical in shape and allowed to cool. A sample for chemical analysis was taken and the chemical composition of the lead alloy was verified at Geology laboratory in Abubakar Tafawa Balewa University, Bauchi. The result of the chemical analysis is as shown in table 1. A high-low-temperature thermo-mechanical treatment process used for non-ferrous metals was employed for this study. This kind of treatment involves quenching the heated specimen of a given metal alloy from the temperature above its recrystallization temperature (i.e. deformation temperature), followed by cold deformation (i.e. deformation below the recrystllization temperature of the specimen) and ageing (Novikov, 1978 and Askeland,).

Six (6) as-cast specimen of the lead alloy of size 86.9mm in diameter and 100mm in length were cut. Each specimen was heated to the following temperatures - 100^{o}C, 150^{o}C and 200^{o}C respectively using a metallurgical furnace of capacity of 1400^{o}C. First the one of the specimen was heated to 100^{o}C at the heating rate of 50^{o}C per hour, and on attaining the set temperature, it was soaked at this temperature for 1 hour to allow the specimen to assume a single-phase structure. Then the specimen was removed from the furnace and quenched in water. The specimen was then extruded to a size 9.65mm in diameter at a speed of deformation of 3mms^{-1}. Tensile test was carried out on the specimen at the national metallurgical development centre, Jos to determine the ultimate strength and the percentage elongation of the treated specimen. This procedure was repeated for this specimen but at the following speed of deformation- 0.7mms^{-1}, 1.1mms^{-1}, 1.5mms^{-1}, 1.9mms-1 and 2.3mms-1; and other die sizes of 6.35mm and 5.35mm. The process was repeated for the as-cast specimen (i.e. control specimen) and those specimens treated at 150^{o}C and 200^{o}C. After the tensile test of the extruded alloy, toughness and macroscopic work-hardening rate were determined from ultimate strength, and uniform elongation; and true stress and strains. In other words, toughness, U_T was determined from a correlation proposed by Johnson and Meltor in 1973 (Askeland, 1925). It is as presented below:

$$U_T = \partial * \sigma_{UTS} \tag{1}$$

Where: σ_{UTS} = the ultimate strength, ∂ = either is uniform elongation or elongation at fracture.

Macroscopic work hardening rate HR was determined using a formula proposed by Tempus Calles and Scharf in 1991(Benjamin et al, 1987). It is as presented below:

$$\mathrm{HR} = \frac{\sigma_2 - \sigma_1}{E_2 - E_2}. \tag{2}$$

Where: σ_2 and σ_1 are stresses as at strains ε_2 and ε_1.

RESULTS AND DISCUSSIONS

Results

The results of the experiment carried out on the recycled lead alloy are shown in tables 1, 2, 3, 4, and 5. Table 1 is the result of the chemical analysis carried out on the recycled lead alloy to determine it chemical composition and percentage (%) concentration of each element in the alloy. Tables 2, 3, 4, and 5 are the results showing the toughness and macroscopic work hardening rate of the treated specimens.

DISCUSSION OF THE RESULTS

Effect of Deformation

Toughness shows positive dependence on deformation. From table 2, for an increase in the deformation from 98.8% to 99.5%, at room temperature and stain rate of $1.1\text{x}10^{-1}\text{s}^{-1}$, the toughness increases from 7.67MN/m^2 to 8.66MN/m^2. Though at a deformation of 99.7% for the same temperature and strain rate, the toughness is 6.24MN/m^2. Similar observations are made for the other temperature and strain rates as shown in tables 2, 4 and 5 or Figure 1. Also the macroscopic work hardening depends on deformation. From tables 2, it is observed that for deformation of 98.8%, 99.5% and 99.7% for strain rate of $0.3\text{x}10^{-1}\text{S}^{-1}$, the macroscopic work hardening rate are 107.69MN/m^2, 282MN/m^2 and 285MN/m^2 respectively. This increase in macroscopic work hardening rate even at high amount of deformation may be as a result of increase in the dislocation density.

Effect of Strain Rate

Again from table 2, for increase in strain rate from $0.3\text{x}10^{-1}\text{S}^{-1}$ for a deformation of 98.8%, the toughness increased. For example, at strain rates of $0.3\text{x}10^{-1}\text{S}^{-1}$, $0.7\text{x}10^{-1}\text{S}^{-1}$, and $1.1\text{x}10^{-1}\text{S}^{-1}$, the toughness are 4.45MN/m^2, 6.40MN/m^2 and 6.67MN/m^2 respectively. Though at a strain rate of $2.3\text{x}10^{-1}\text{S}^{-1}$, the toughness is 7.38MN/m^2. This decrease in toughness shows that at high strain rate, recovery, which is as a result of softening due to re-crystallization, may take place. Results of table 3,4 and 5 shows similar behaviours. In like manner, macroscopic work hardening rate at room temperature decreases with increase in strain rate.

Effect of Temperature

Tables 2, 3, 4 and 5 and Figure 1, show that toughness increases with increase in temperature, although at temperature of 2000°C, toughness decreased in toughness. It can be inferred from this result that at high temperature, softening due to dynamic recovery or recrystallization might have occurred; which in turn reduces the dislocation density, hence decrease in toughness. It is also observed that for specimen subjected to deformation of 98.8%, macroscopic work hardening rate. H.R. increases with increase in temperature. For instance, for increase in temperature from room temperature to 100°C, at strain rate of $0.3\text{x}10^{-1}\text{S}^{-1}$, the macroscopic work hardening rate increases from 107.69MN/m^2 to 114.2MN/m^2. Similar observations were noted for temperature of 150°C and 200°C. However, for specimen subjected to 99.5%, macroscopic work hardening rate decreased from 282MN/m^2 to 125MN/m^2 for an increase in temperature from room temperature to $100^{o}C$ at strain rate of $0.3x10^{-1}S^{-1}$. It can be inferred from this results that at high temperature, softening due to dynamic recovery or recrystallization occurs.

CONCLUSIONS

Although increasing deformation rate and temperature increases the toughness of the alloy considered, the extent to which each of these factors affects the mechanical property differs. It is also observed that macroscopic work hardening rate increases with increase in deformation. For deformations of 98.8%, 99.5% and 99.7% for strain rate of $0.3x10^{-1}S^{-1}$, the macroscopic work hardening rates are $107.6MN/m^2$, $282MN/m^2$ and $285.7MN/m^2$ respectively. In like manner, toughness increases with increase in temperature. This shows that to achieve improved mechanical properties of the lead alloy deformation, deformation rate and temperature can be varied.

Table 1: Chemical Composition (Wt%) of the Lead Alloy

Elements	Zn	Mn	Cd	Co	Cr	Pb	Cu	Fe	Ni	Ag
Concentration (mg/l)	1.25	0.03	0.05	0.06	0.01	907.5	12.66	0.16	0.30	0.37
Weight percentage (%)	0.12	0.003	0.005	0.006	0.001	90.75	1.266	0.016	0.03	0.037

Table 2: Toughness and Macroscopic Work Hardening Rate at Temperature = Room Temperature

Strain Rate S^{-1} $x10^{-1}$	Specimen Size = 9.65mm		Specimen Size = 6.35mm		Specimen Size = 5.35mm	
	U_T (MN/m^2)	H.R (MN/m^2)	U_T (MN/m^2)	H.R (MN/m^2)	U_T (MN/m^2)	H.R (MN/m^2)
0.3	4.45	107.69	4.42	282.00	3.58	285.7
0.7	6.40	86.44	6.60	126.15	5.26	147.1
1.1	7.67	62.86	8.66	140.26	6.24	347.1
1.5	8.68	62.22	9.66	120.00	6.87	333.3
1.9	9.55	94.40	10.76	170.00	7.56	150.0
2.3	7.38	87.78	10.11	88.20	7.77	200.0

Table 3: Toughness and Macroscopic Work Hardening Rate at Temperature = $100^{o}C$

Strain Rate S^{-1} $x10^{-1}$	Specimen Size = 9.65mm		Specimen Size = 6.35mm		Specimen Size = 5.35mm	
	U_T (MN/m^2)	H.R (MN/m^2)	U_T (MN/m^2)	H.R (MN/m^2)	U_T (MN/m^2)	H.R (MN/m^2)
0.3	4.92	114.2	4.45	126.0	3.60	230.0
0.7	7.31	244.4	7.62	126.0	5.26	506.3
1.1	8.74	266.7	9.56	128.7	6.77	287.0
1.5	10.98	376.5	11.94	134.6	7.85	198.7
1.9	12.19	391.7	13.48	164.4	8.44	546.7
2.3	9.12	338.4	13.52	230.8	8.76	273.0

Table 4: Toughness and Macroscopic Work Hardening Rate at Temperature = $150^{o}C$

Strain Rate S^{-1} $x10^{-1}$	Specimen Size = 9.65mm		Specimen Size = 6.35mm		Specimen Size = 5.35mm	
	U_T (MN/m^2)	H.R (MN/m^2)	U_T (MN/m^2)	H.R (MN/m^2)	U_T (MN/m^2)	H.R (MN/m^2)
0.3	5.38	157.5	4.48	126.4	3.10	205.5
0.7	8.96	171.4	8.21	126.0	5.76	409.0
1.1	11.50	320.0	11.18	127.6	7.14	278.8
1.5	13.36	494.0	13.97	127.7	8.66	111.8
1.9	15.34	440.0	16.94	164.2	9.36	116.4
2.3	15.40	357.0	17.57	136.4	8.93	80.0

Table 5: Toughness and Macroscopic Work Hardening Rate at Temperature = 200°C

Strain Rate S^{-1} $x10^{-1}$	Specimen Size = 9.65mm		Specimen Size = 6.35mm		Specimen Size = 5.35mm	
	U_T (MN/m^2)	H.R (MN/m^2)	U_T (MN/m^2)	H.R (MN/m^2)	U_T (MN/m^2)	H.R (MN/m^2)
0.3	2.90	226.4	3.00	227.3	2.97	374.6
0.7	4.94	224.6	4.66	219.3	4.45	409.1
1.1	7.23	192.3	7.76	226.5	5.51	278.1
1.5	9.36	147.7	9.42	175.7	6.62	260.0
1.9	10.67	105.7	11.27	148.9	7.28	258.9
2.3	11.16	172.6	11.57	216.0	7.00	115.0

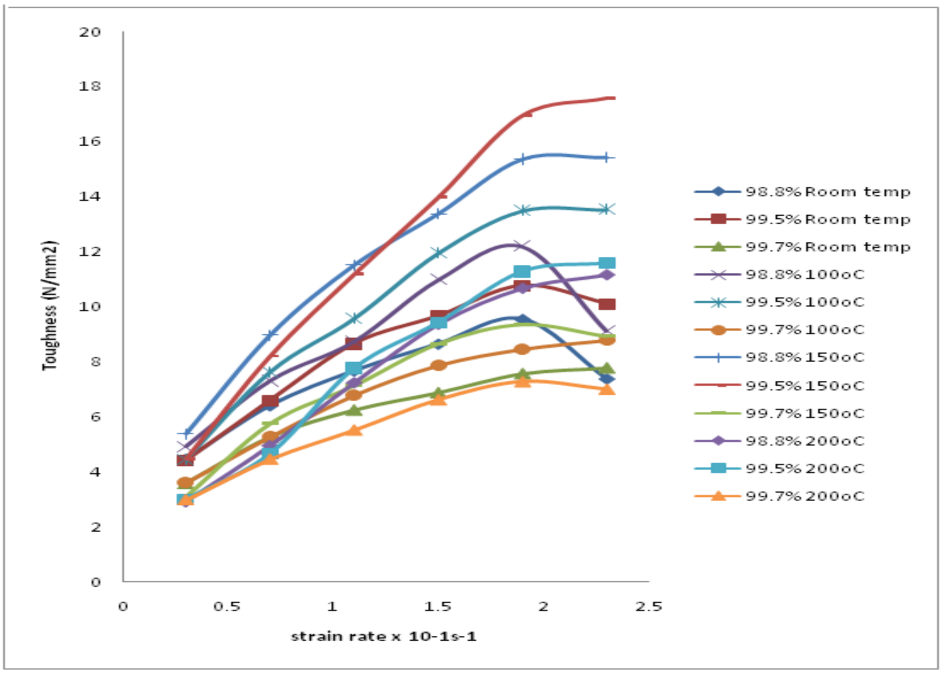

Figure 1: Toughness versus Strain Rate at Different Temperatures and Deformation

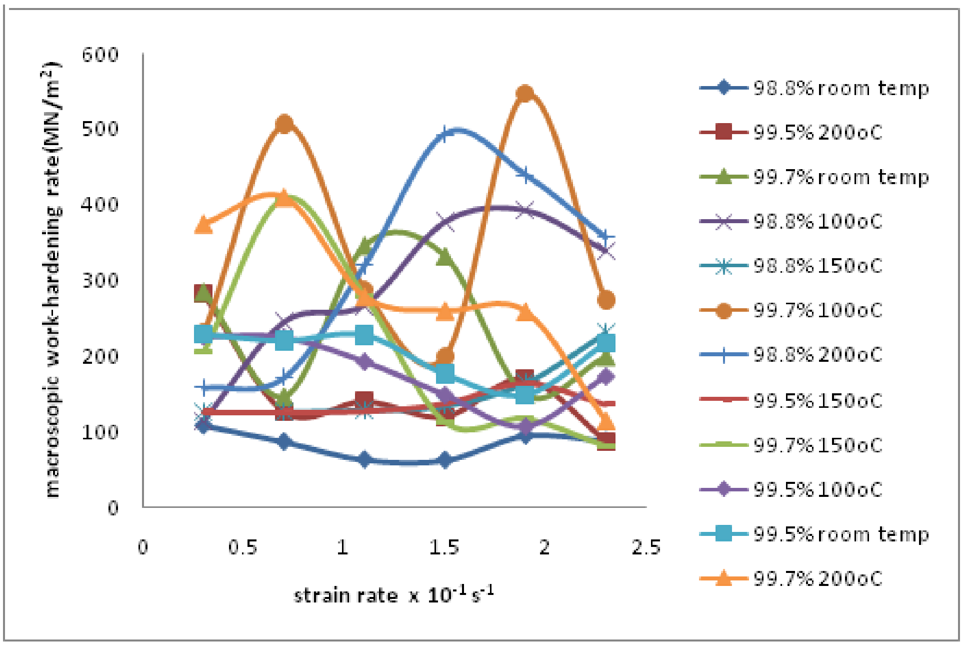

Figure 2: Macroscopic Work-Hardening Rate versus Strain Rate

REFERENCES

1. Askeland R. (1925). The Science and Engineering of Materials Macmillan Publishing Company, New York, pp. 401-425.
2. Benjamin W.N. Drapper A.B. Wysk R.A. (1987). Modern Manufacturing Process of Engineering. Hill book Co. Singapore, Pp 122-125.
3. Jatau, J.S., Datau S.G. (2002). The Influence of Thermo-mechanical Treatment on some Mechanical Properties of Lead alloy. Nigerian Journal of Engineering. Vol. 10, No. 1pp.
4. Jatau, J.S., Tokan, A., and Yau, M. (1999): Improving the surface hardness of locally produced low carbon steel using charcoal and Barium carbonate as the carbonaceous compound. Bulletin of Science Association of Nigeria. 22: 99-103
5. Jastrebski, Z. D (1987): The nature and properties of engineering materials, 3rd edition, New York, John Willey, Pp: 71 120
6. Laktin Y. (1986). Engineering Physical metallurgy and Heat Treatment, Mir Moscow, pp. 372-374.
7. Liewellyn D. T. (1997). Work Hardening Effects in Austenitic Stainless Steels. Journal of Materials Science Technology B 13. 389-390.
8. Liu Jinke, Jiang Zhonghao and Lian Jianshe(1991): Influence of predeformation on Micostructure and Mechanical properties of 1020 dual phase steel. Journal of Materials Science Technology, 7:510-531
9. Mabuchi M., Kubota K. Higashi K. (1996): Elevated Temperature Mechanical Properties of magnesium alloys containing Mg_2Si. Journal of Materials Science and Technology, 12:35-60
10. Novikov, I. (1978). Theory of Heat Treatment of Metals, Mir, Moscow, pp. 407-414
11. Rajan, T.V., Sharma, C.P., Ashok S.(1988): Heat Treatment Principle and Techniques, Prentice hall limited, India, p_p 184-190
12. Sircar S., Humpreys(1996): Modelling Microstructural deformation in two phase aluminium alloys after hot deformation. Journal of Material Science Technology.