THERMAL STRAIN AND EXPANSION COEFFICIENT OF PbSb ALLOY UNDER STATIC AND DYNAMIC LOADING

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Abstract

Thermal–mechanical behavior of PbSb alloy subjected to static and dynamic loading in the temperature range 30-200 ^{o}C and different loading schemes has been investigated. The take up strain is Hookian up to 100 ^{o}C and transfer to creep behavior for higher temperatures (<100-200 ^{0}C) and loads as penetration of the applied load through the alloy sample prevails due to the transformance of some solidous phase to liquidous phase near the eutectic temperature. The strain rate sensitivity factor "m"-value serves to monitor the thermal strain and its effect on the overall strain thermal and mechanical. Thermal expansion coefficient is found to remain nearly unchanged up to certain temperature regardless of the applied stress. This may partly due to the compensation between extension and penetration such that the net change becomes insignificant. It is suggested that the dimensional stability is largely affected by excessive loading stress rather than by environmental temperature.

Keywords: Lead-Antimony alloys; TMA; Thermal stability.

Introduction

Lead base alloys have been in common use for a very long time due to their ease of casting, reasonable hardness as they are widely used in the grids of positive electrodes of a lead-acid battery. The Pb-Sb alloys are strong and creep-resistant at ambient environment and are capable of resisting the stresses of the charge-discharge reactions[1,2].

Comparative study of creep behavior of Pb 8%Sb alloy with oxide dispersed Pb has shown some preference in the creep behavior of the oxide dispersed Pb in comparison with the Pb 8%Sb on a sacrifice of very slight increase in the internal electrical resistance of the accumulator [3].

Dimensional stability of the Pb/Sn eutectic alloys subjected to thermal cycling show anisotropic dimensional change resulted from elastic, plastic and creep strain [4].

Literally little work is directed on the study of the creep behavior of Pb/Sb Eutectic alloy under the combined thermal – mechanical effects i.e. the TMA analysis. It is thought that mechanical loading whether static or dynamic in the presence of thermal environment may conduce an insight on the thermal strain behavior and also on the thermal expansion coefficient which is the theme of this work.

Experimental

Commercial purity PbSb alloy (99%) in the form of bars were obtained from local market. XRD analysis made on Shimadzu 6000 diffractometer showed that the composition of the alloy was in the eutectic phase at 11 at.% Sb Fig.(1). The bars were machined to the desired dimension with φ 6 mm in diameter and 12 mm in length. Precise dimensions of samples were obtained by using digital vernier. The samples were tested in the computer controlled thermo-mechanical analyzer Linseis type PT1000 from 30 to 200 ^{o}C at no applied load and at applied variable load bearing constant low frequency of 0.5 Hz in the penetration mode.

Results and Discussion

Typical thermo-mechanical output chart represented by the change in length and coefficient of thermal expansion for PbSb is shown in Fig.(2). The behavior of strain as a function of temperature at different applied stresses (load divided by area) is shown in Fig.(3). The curves signify that up to 100 ^{o}C, the alloy withstand all the applied stresses maintaining the dimensional stability i.e. stress is transformed totally to elastic strain. Whereas above 100 ^{o}C and up to 200 ^{o}C, the alloy endures a low stress (5 MPa) with apparent dimensional stability, but as the stress exceeds the (5 MPa) range, the alloy starts to loose its dimensional stability at progressive pace with the action of higher stresses particularly as the temperature approaches 200 ^oC. The impairment of dimensional stability referred as penetration of load through the alloy is a result of the alloy entering the eutectic temperature region (phase diagram PbSb [5]) where some of the phase systems constituting the eutectic reaction approach the transference from solidous region to the liquidous region. This was clearly seen in the sample tested in the environment of 250 ^oC (the eutectic temperature). The results of this run was excluded because the load applied was able to penetrate through the alloy sample causing cleavage in the sample.

In order to look at the effect of load and temperature on the total strain endured by the alloy, the results are extracted from Fig.(3) and are presented in Table (1). It is noted that maximum total strain recorded at the highest temperature (200 ^oC)and stress (10 MPa) is linearly decreasing as both temperature and stress decrease until the total strain reaches nearly fixed values at 100 ^oC for the different stresses employed.

Thermal and mechanical strains

The mechanical strains ε, which is visualized by the Hookian behavior as:

$\varepsilon = \sigma / E$ .... (1)

where E is the elastic modulus and σ the applied stress, necessitate the use of elastic modulus of PbSb which could not be found in the relevant literature. Thus the modulus was calculated according to the rule of mixtures by making use of the elastic moduli of Pb and Sb from [6] and the eutectic composition [5] and the corresponding strains are given in Table (2).

Thermal strain is visualized by the penetration effect of the applied load calculated from the non-liner parts in Fig.(3). The results are also tabulated in Table (2).

It is clear that the strain is dominated by the thermal effect in comparison to the mechanical effect. This means that the PbSb alloy yields readily to small piercing loads at temperature well below the eutectic temperature.

Strain sensitivity can be evaluated following the "m" value defined by [7] as:

$m = d \ln \sigma / d \ln \varepsilon$ .... (2)

σ is the stress and ε is the strain.

Values of "m" are calculated for different thermal cycles and stresses as in Table (3).

Results from Table (3) clearly demonstrate that the PbSb alloy is thermal strain sensitive since "m"-values becomes smaller at higher thermal cycling.

Thermal Expansion Coefficient

Thermal expansion was evaluated by the static regime (no load) and the dynamic regime (with load and frequency) according to the formula $\alpha = \Delta L / L_0 \Delta T$. In the static regime α was evaluated up to 200 ^oC, but in the dynamic regime α was evaluated up to 100 ^oC. Results of thermal expansion coefficients are shown in Fig.(4). It is noted that α remain nearly constant in the temperature range up to 100 ^oC whether load or no load was applied. However, at up to 200 ^oC and for no load regime, α appear to be slightly decreasing. This apparent decrease is due to the gravity action of the testing penetrator which reflects on the net change in length ΔL.

Thus and for this reason α can not be evaluated accurately from dynamic loading above 100 ^oC as the penetration effect is pronounced.

Conclusion

1. Strain uptake of the alloy by combined thermal-mechanical influence is very effective at temperatures nearing the Eutectic temperature as the alloy become vulnerable to penetration.
2. The strain sensitivity "m"-values are an indicator to the degree of thermal stability.
3. Thermal expansion coefficient is influenced in succession by the testing mode, temperature and loading.

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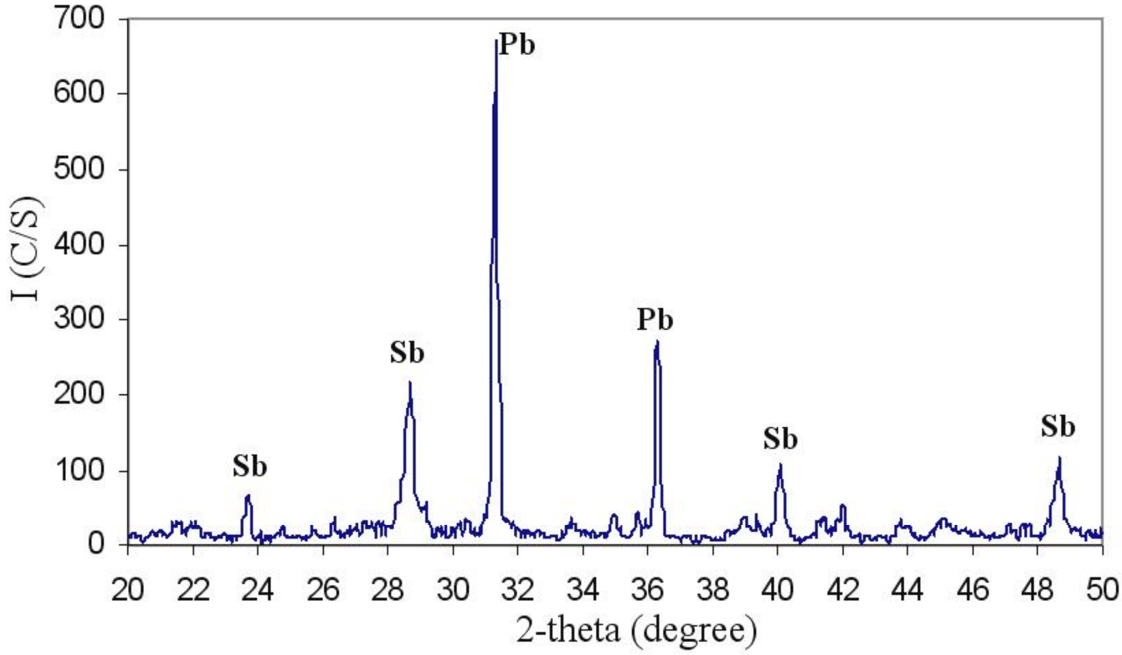

Fig.(1) : XRD Spectrum of Eutectic PbSb alloy.

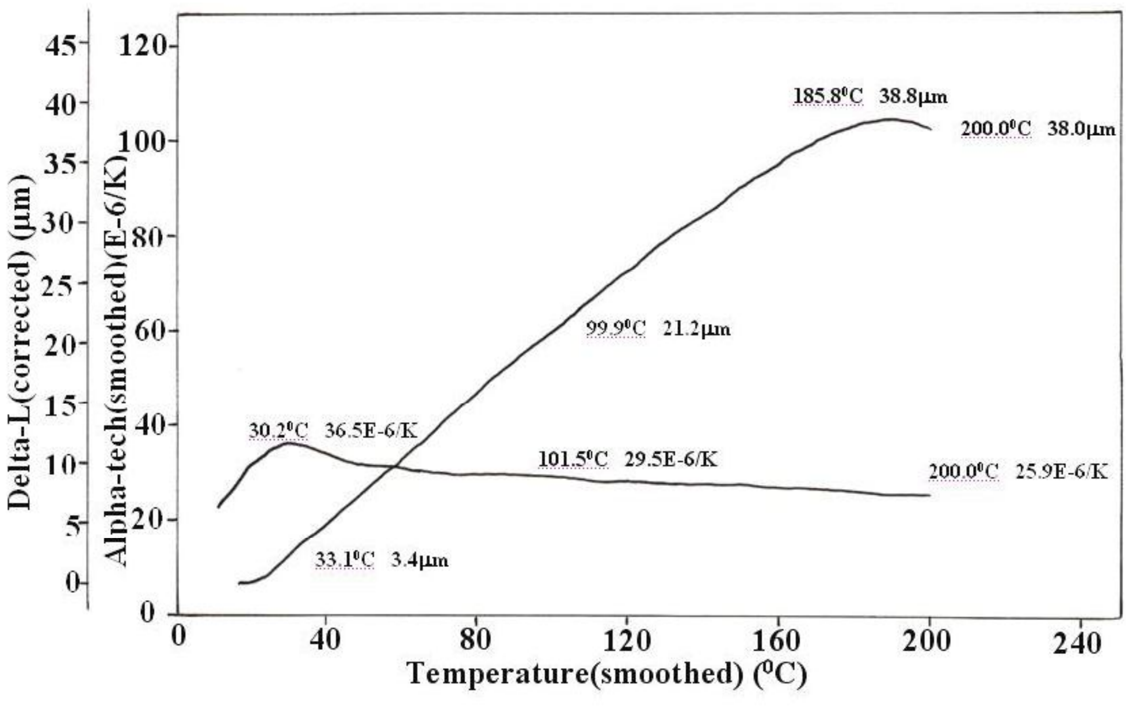

Fig.(2) : Typical TMA chart for PbSb alloy showing multi-axes (ΔL and α) behavior as a function of temperature.

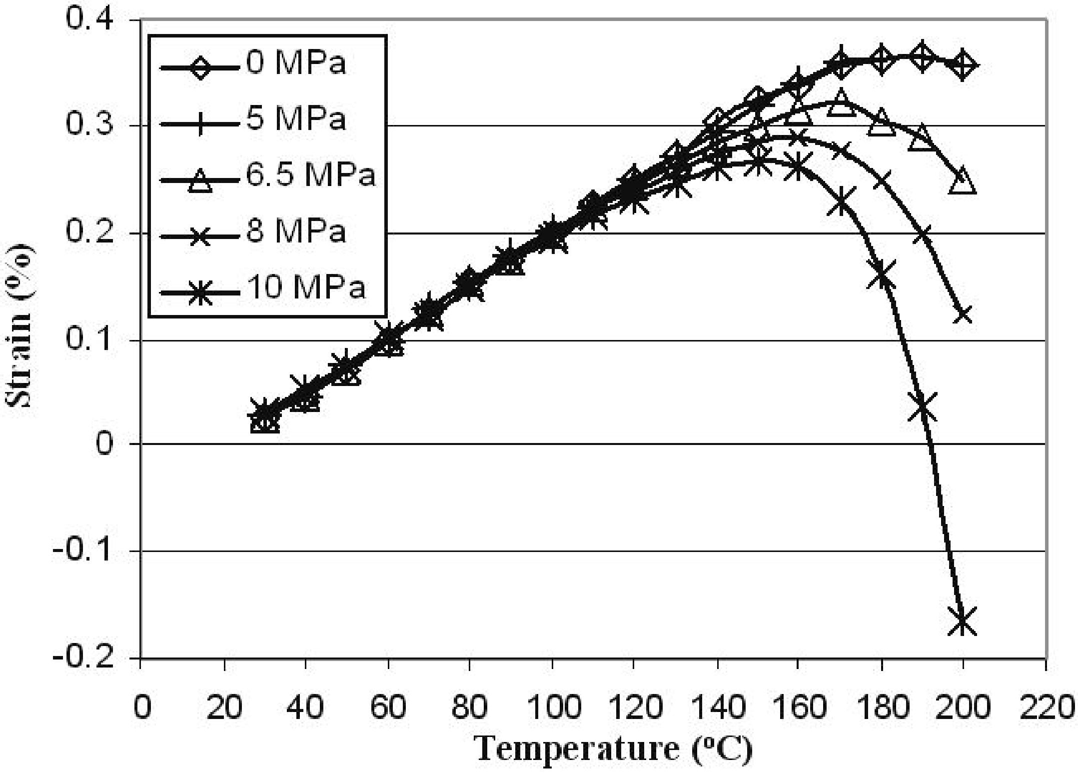

Fig.(3) : Strain behavior vs. temperature for PbSb alloy at different applied stresses.

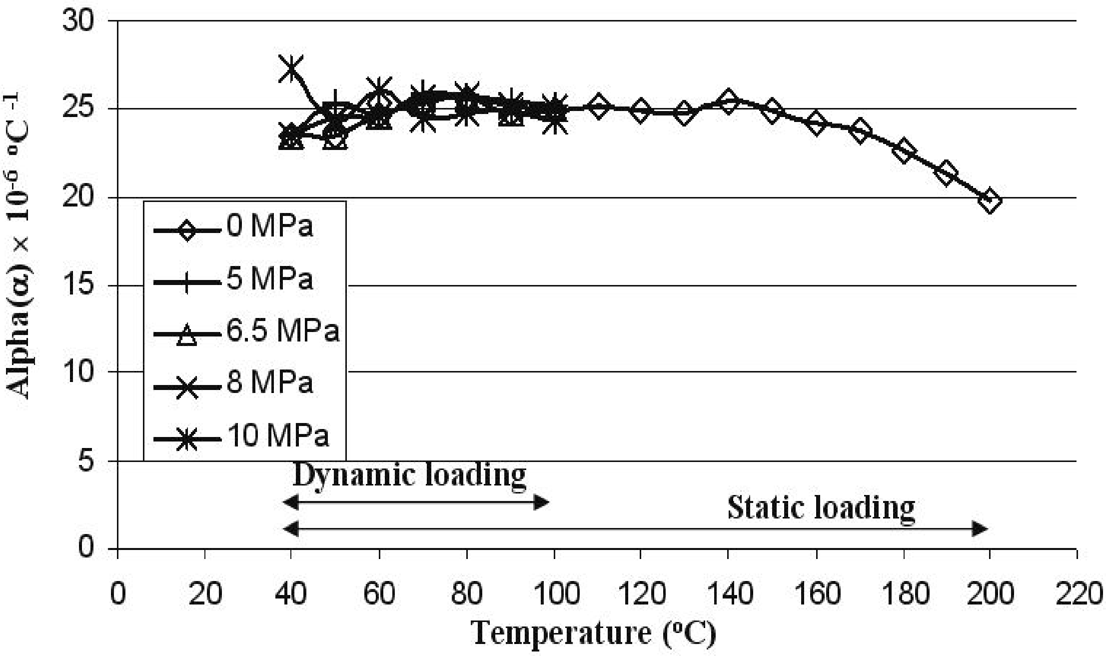

Fig.(4) : Coefficient of thermal expansion of PbSb alloy vs. temperature for different loading stresses.

Table (1)
Effect of stress and temperature on total strain endured by PbSb (extracted from Fig.(3)).

Total strain (%)		**Temperature (^{0}C)**										
		100	110	120	130	140	150	160	170	180	190	200
Stress (MPa)	0	0.199	0.227	0.249	0.272	0.305	0.324	0.338	0.357	0.361	0.364	0.372
	5	0.202	0.225	0.249	0.272	0.296	0.320	0.333	0.352	0.362	0.364	0.372
	6.5	0.200	0.225	0.246	0.265	0.285	0.300	0.315	0.322	0.338	0.354	0.395
	8	0.201	0.225	0.240	0.258	0.275	0.285	0.290	0.303	0.330	0.380	0.457
	10	0.194	0.216	0.233	0.247	0.263	0.268	0.272	0.305	0.375	0.499	0.701

Table (2)
Mechanical and thermal strain of PbSb at different stresses and temperatures.

Stress (MPa)	**Mechanical strain (%) (Calculated from eq.1)**	**Strain (%) (from Fig.(3)) at R.T.**	**Fraction of strain (%) (Correspond to penetration)**		
			180 ^{0}C	**190 ^{0}C**	**200 ^{0}C**
5	0.023	0.028	0.12	0.14	0.15
6.5	0.030	0.026	0.12	0.15	0.19
8	0.037	0.027	0.13	0.18	0.26
10	0.046	0.031	0.17	0.30	0.50

Table (3)
Strain sensitive "m"-values for different thermal cycles and stresses for PbSb alloy.

m		**Temperature (^{o}C)**			
		R T	**180**	**190**	**200**
Stress (MPa)	6.5	0.9999	0.97	0.95	0.87
	8	0.9991	0.90	0.82	0.65
	10	0.9950	0.81	0.43	0.34

الخلاصة

تم دراسة السلوك الحراري – الميكانيكي لسبيكة PbSb معرّضة لتحميل ستاتيكي وديناميكي في درجـــات حـــرارة بين 30 إلى 200 ^{o}م وخطط مختلفة للتحميل.

تبين بان الانفعال المأخوذ يخضع لقانون هـــوك لغايـــة 100 ^{o}م ويتحول إلى سلوك زحف عند درجـــات حـــرارة وتحميل عاليان بسب اختراق الحمل المُسلط للسبيكة، ويُفسّر على ضوء تحول بعض من الطور الـــصلب إلـــى الطـــور السائل قرب درجة الحرارة اليوتكتيكية. وجد بان قيمة عامل معدل حساسية الانفعـــال "m" يخـــدم لمراقبـــة الانفعـــال الحـــراري وتـــأثيره علـــى مجمـــل الانفعـــال الحـــراري والميكانيكي. وجد بان معامل التمدد الحـــراري يبقـــى دون تغير لغاية درجة حرارة معينة بصرف النظر عن الإجهـــاد المُسلط. ويعود السبب جزئياً إلى التعـــويض بـــين التمديـــد والاختراق بحيث تكون محصلة التغير في الاستطالة غيـــر ملحوظة.

اقترح بان الاستقرارية البعدية تتأثر كثيراً بفرط الإجهاد المُسلط بدلاً من بيئة درجة الحرارة.

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