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Measurement of surface parameters for Sn-3.8Ag-07Cu solder

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ABSTRACT

Because of their expanding importance in evaluating surface properties, optical non-destructive technologies for 3D surface metrology have gained importance in research and engineering in recent years. In this study, optical 3D Infinite Focus measurement (IFM) system based on the technology of focus-variation was used for qualitative and quantitative evaluation of alloy Tin (Sn). The capabilities of the system on a series of applications ranging from surface roughness, waviness, bearing ratio, determining of depth and diameter of Sn-0.7Cu solder was demonstrated. Samples used in this study were subject zato micro-hardness tests conduct on a soft material (alloyed Sn) using micro hardness indeed. Sample differences in surface morphology were caused by variations in the load and application that the samples were subjected to during the indentation test. Plotting the soft material's surface roughness, waviness, and bearing ratio required the use of indentation testing under load, as determined by the micro hardness tool (Sn-0.7Cu). Results from two measurements were used to determine the diameter, depth, surface roughness, waviness and bearing ratio of the alloyed Sn (Sn-0.7Cu) using waviness, roughness and bearing ratio analysis. In order to construct their 3D profile and analyze their surface roughness and waviness of the dented soft material, samples were further examined based on their surface parameter. Results also showed that the unreformed materials processed elastic properties when subjected to some amount of force under the influence of load.

Key words: Fracture surface roughness, microhardness, surface waviness, Optical properties, Tin alloy.

الملخص:

بسبب أهميتها المتزايدة في تقييم خصائص السطح، اكتسبت التقنيات البصرية غير المدمرة لقياس السطح ثلاثي الأبعاد أهمية في البحث والهندسة في السنوات الأخيرة. في هذه الدراسة، تم استخدام نظام قياس التركيز اللانهائي البصري ثلاثي الأبعاد (IFM) المعتمد على تقنية تباين التركيز للتقييم النوعي والكمي لسبائك القصدير (Sn). تم عرض قدرات النظام على سلسلة من التطبيقات التي تتراوح بين خشونة السطح والتموج ونسبة التحمل وتحديد العمق وقطر اللحام Sn−0.7Cu. خضعت العينات المستخدمة في هذه الدراسة لاختبارات الصلابة الدقيقة التي أجريت على مادة ناعمة (سبائك Sn) باستخدام الصلابة الدقيقة بالفعل. كانت اختلافات العينة في شكل السطح ناتجة عن الاختلافات في الحمل والتطبيق التي تعرضت لها العينات أثناء اختبار المسافة البادئة. يتطلب رسم نسبة خشونة سطح المادة الناعمة، والتموج، ونسبة التحمل استخدام اختبار المسافة البادئة تحت الحمل، على النحو الذي تحدده أداة الصلابة الدقيقة (Sn−0.7Cu). تم استخدام نتائج عينتان قياس لتحديد القطر والعمق وخشونة السطح والتموج ونسبة التحمل للسبائك (Sn−0.7Cu) باستخدام تحليل التموج والخشونة ونسبة التحمل. من أجل بناء ملف تعريف ثلاثي الأبعاد الخاص بها وتحليل خشونة سطحها وتموج المادة الناعمة المنبعجة، تم فحص العينات بشكل أكبر بناءً على معامل سطحها. كما أظهرت النتائج أن المواد غير المعالجة عالجت خواصها المرنة عند تعرضها لقدر من القوة تحت تأثير الحمل.

الكلمات المفتاحية: خشونة سطح، الصلابة الدقيقة، تموج السطح، الخصائص البصرية، سبائك القصدير

Introduction

Soft materials are most important in a wide range of technological applications. They are used as structural and packaging materials, foams, and adhesives. A typical example of a soft material that is of great interest is stanuum, otherwise known as tin (Sn), which is an element in-group 14 of the periodic table having an atomic number of 50. Tin is not easily oxidized in the air, making it suitable for coating other metals to prevent corrosion. Tin shows chemical similarity to neighboring group elements such as germanium and lead. Sn has two possible oxidation states: +2 and stable +4. Ten stable isotopes make up the element tin, which ranks 49th in the periodic table and has the most stable isotopes of any element. Sn is obtained mainly from the mineral cassiterite as tin dioxide (SnO_2). It comprises 85% to 90% of the pewter used for corrosion-resistant plating of steel and in food packaging (tin cans). (Molodets& Nabatov, 2000).

Sn is among the first alloys used on a large scale since 3000 BC. The production of pure metallic Sn is believed to have started since 600 BC in the form of pewter consisting of 85% and 90% of Sn, copper, antimony, and lead, and was commercially used for the manufacturing of knives, forks, and spoons from the Bronze Age until the 20th century. Currently, Sn has found its application in many alloys, notably tin/lead soft solders (Molodets& Nabatov, 2000). It is also used in capacitors, electrodes, fuse wires, and ammunition. Moreover, Sn alloys such as soft solder, bronze, and phosphor bronze are important in the electrical and automotive industries.

Measurement of geometrical parameters of soft material is among the main prerequisites for quantitative analysis in a number of studies in material science and biological research, especially during the analysis of the relationship between function and structure. However, a wide variety of methods exist for estimating the geometrical characteristics of microscopical structures based on the evaluation of stacks of perfectly registered sections (Kubinova & Opatrny, 1999).

Digital images of perfectly registered stacks of serial optical sections from thick samples recorded by confocal and two-photon microscopes represent suitable data for quantitative measurements as well as for computer three-dimensional (3D) reconstructions that can be made without the necessity to solve the tedious problem of alignment of images of successive sections (Russ,1990 & Pawley, 1995). Although the role of 3D imaging is well known, its advantages for measuring the geometrical characteristics of microscopical structures have not yet been fully recognized (Rigaut & Vassy, 1992). However, in comparative studies, it is often desirable to obtain quantitative information on the geometry

of the structure of interest, such as the volume and/or surface area of sample components, rather than its visualization.

Generally, surface roughness parameters have been used to describe material surfaces, while roughness parameters were formulated to characterize surface features (Bello,1987& El-Daly,2011). A new surface roughness metric known as the bearing product was developed by Bello and Walton (Ţălu, 2015) and is the product of average peak width and Ra. This parameter has a functional relationship with the coefficient of friction. Based on a 3D surface characterization (Singh, 2005), the amplitude parameter Sq (RAM deviation of surface), spatial parameters Sds (density of summits), and Std (texture direction) have important roles in determining the frictional behavior of surfaces. However, two groups of automatic digital methods based on image processing and surface triangulation will be discussed in the present work.

There is still a high necessity for an in-depth study of allying elements such as Ag on the surface properties of Sn-Cu solder alloy. Such studies play a vital role from the standpoint of predicting the performance of soft materials under service conditions. (EL-Daly & EI-Taher, 2011) reported the first attempt· It was found that the proper additions of Co, in, and Ag into Sn-Zn eutectic solder are beneficial to encourage the formation of new interceramic marble collections (IMCs). The aim of the present work is to obtain quantitative information about the effect of surface properties such as surface roughness and waviness on alloyed Sn. Advanced research has enhanced comprehension of the three-dimensional surface microtexture of thin films, leading to the advancement of materials with significant technological implications. (Kaspar, 2019 & Knápek,2017). Scientific attention is focused on the central role of advanced techniques in characterizing. (Stach, 2017& Arman, 2015). Research has indicated that the surface microtexture in three dimensions can be effectively characterized using stereometric analysis. (Ţălu,2016 & Yadav,2015). AFM imaging can yield exceptional outcomes in the study and examination of nanostructured surfaces, particularly thin films, using a limited number of surface parameters. (Shikhgasan,2015& Weibel,1979). an investigation of the optical and topographical parameters such as surface roughness, bearing ratio, and waviness of the alloyed soft material using IFM will be conducted. Findings from this study could be used to develop alloys for different electronic packaging applications, such as wave soldering on single-side printed circuit boards.

Different methods are used to quantify the image of the material under study. However, two groups of automatic digital methods based on image processing and surface triangulation will be discussed.

. **Firstly; Stereological Methods**

Stereological methods are precise tools for the quantitative evaluation of the structures of 3D objects. Image evaluation of stereological devices is based on observations made on a 2-D section (Serra,1982) using 0-D (point) or 2-D (planar) test probes and counting the number of test points that fall within a given structure or the number of intersection points of test lines with the structure surface. For contemporary stereology, the 3-D geometric features of the examined sample can be analyzed if the microscopic field of view is focused through a rectangle viewer. However, by using special software, it is possible to generate different virtual test probes at random positions and orientations within the stack of sections and apply them directly to the image data.

Secondly; Image Processing Based Method

It is an automatic measurement of the 3-D geometric features of an object that can be applied directly to binary images obtained through the automatic segmentation of grayscale images captured by a microscope. Automatic segmentation is a procedure for processing a source digital grayscale image and refers to the data structure of numerical values in the spatial grid of image elements called pixels in 2-D or vowels in 3-D that results in a binary image in which the foreground elements are part of the object under study (Meyer, 1992). The validity of the results of such automatic measurement, their unbiasedness, and precision depend mainly on the precise description of the object by the model. Finally, the 3-D image processing, using spatial information can be more effective and robust than the 2-D processing of individual slices. The basic algorithms of 3-D image processing can be derived from those used in 2-D image processing in a straightforward way (Chen, 2008).

Materials and Method

Ternary Sn-3.8Ag-07Cu solder was applied as a basic material using the three-sided pyramid diamond indenter, both for indentation testing and as the tip during IFM imaging. Images acquired by IFM were used to locate the desired phases of interest, measure the surface roughness, waviness, and bearing ratio, as well as the diameter and depth of the indents from the phase boundaries of the soft material, and model the 3D image of the sample. The area function of the indenter (projected area as a function of depth) and the system compliance were periodically checked throughout testing. A similar strategy has been noted and used as an ideal strategy to evaluate the surface parameters of soft materials (Campos, 2008).

Microhardness tests (referring to static indentations) using a diamond pyramid indenter with an external load ranging from 10 to 250 gf were made with varying experimental loads from 10 to 25 gf, which is the magnitude force exerted on one kilogram of mass by a 9.81 m/s^2

gravitational field. The micro-hardness number was calculated by dividing the applied load (gf) by the indented surface area (mm^2) using the expression shown in equation (1):

$$HV = \frac{2f\ sin\frac{136°}{2}}{d^2} \qquad (1)$$

Where: *f*= Load in gf, *d*= Arithmetic mean of the two diagonals, and HV= micro-hardness.

For the surface indentation of the soft material, a micro-hardness test was conducted on two samples of soft material (Sn-3.8Ag-0.7Cu) using a square base diamond indenter at an angle of 130 degrees between the opposite faces. Firstly, the soft material was placed on an anvil driven by a threaded screw. The screw was used to properly align the sample (soft material) vertically opposite the indenter and was subjected to a load range of 10 to 250 gf. The applied load lasted between 10 and 15 seconds, after which the two diagonals (d_1 and d_2) of the indentation left on the surface of the soft material after the removal of the external load, were measured using a microscope, and the average value of each sample was calculated. A high-resolution microscope measured the external load applied to the samples during the micro-hardness test. The 3D images were achieved using soft material (Sn-3.8 Ag-0.7 Cu) after passing through a number of successive stages. The data generated was used for qualitative representation as well as the retrieval of quantitative results.

Results and Discussions

Results from a micro-hardness test of a soft material (Sn-3.8Ag-0.7Cu) that was subjected to localized deformation from indentation. In most materials, plastic deformation is predominant over the surface. Micro-hardness measurement is used for quality control of materials because it is a quick and nondestructive test, especially when the indentations produced by the test are in low-stress areas (Chen,2007). The use of knop or brekovich indenters of various indentation-based materials for soft materials has proven to be effective for assessing surface parameters such as surface roughness, waviness, and bearing of the material. Although there are varieties of methods used to determine the hardness of material, this study uses the Vickers and Knoop hardness test method, which is a modification of the Brinell test to measure the surface hardness of alloyed Sn (Sn-3.8ag-0.7Cu).

To evaluate the hardness of the two investigated samples of soft material, a small diamond pyramid was used to press into a square pyramidal indenter that produces longer and shallower indentations. This low load created a small indent that was measured under a microscope. The measurements for the two samples were taken at high magnification (1000µm) because the indents are small. After the diagonals were measured, the values realized were used to obtain a hardness number (VHN) from the search scheme.

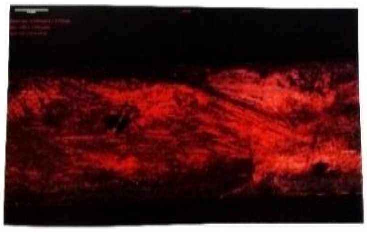
The indentation method is simple and convenient, allowing for a straightforward experimental assessment of surface roughness and waviness using a small number of samples (Campos, 2008& Chen, 2007). However, using this method enabled us to evaluate the surface parameters (surface roughness, waviness, and bearing ratio) of the soft material (Sn-3.8ag-0.7Cu) using a diamond pyramidal indenter that produces shallower and longer indentation under a sharp contact load ranging from 10 gf to 250 gf on two samples under varying loads.

Surface Identification of Sn-3.8Ag-0.7Cu Solder

The two samples of the soft materials (Sn-3.8Ag-0.7Cu) were subject to different loading scenarios. The surface roughness and waviness profile of the sample show varied properties that are dependent on the loading conditions and the applied force. The results from the two loading conditions used were divided into two segments with respect to each sample. The results obtained for each sample are discussed hereafter.

Sample 1

An optical color 3D image obtained from sample 1 at a resolution of 200 µm using IFM is shown in figure 1. The picture appeared to show horizontal traces of a contact stylus instrument that was used for reference measurement of the sample. The values obtained from measuring the diameters were used to obtain the hardness number that is reported for sample 1. The diagonals of the impression were measured, and the values were used to obtain the hardness number that is reported for sample 1. As shown in Table 1, the average indent depth of sample 1 is 6.36 µm, while the average diameter is 147.0 mm. The average surface roughness of the sample is 33.1, while the average waviness profile value is 106.6, respectively. The maximum peak represents the hardness strength of the sample, which is highest at 25 gf. The hardness strength decreases as more load is added to the sample; however, the microscopic deformation of the Sn-3.8Ag-0.7 Cu solder is obvious and is as represented in figure 2 (surface waviness).



(a) (b)

Figure 1: Optical 3D image of (a) sample-1, (b) sample-2

Figure 3 (surface roughness) deformed when subjected to a load of 23 gf and the roughness peak sharply increases as load increases which is the proportional limit of curve however ; linear theory of elasticity using Hooke's law is valid , comparing the initial and final state of the surface waviness and roughness profile of sample 1 , it can be observed that the surface waviness profile (figure2) exhibited slight elastic property which is highest at a load of 25gf and loses this elastic property as more load was added which the surface roughness profile (figure 3) of the same sample exhibited plastic elastic property that sharply increases after deformation at a load of 23 gf and increases with respect to increase in load .

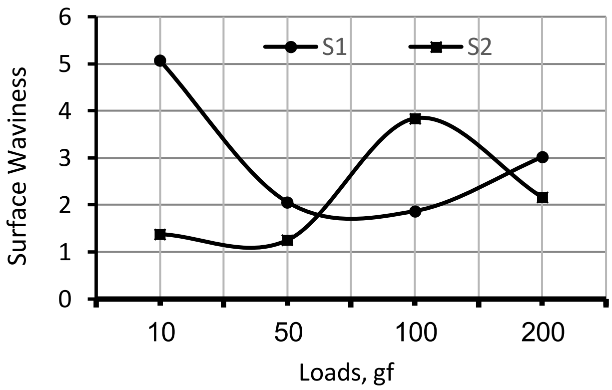


Figure 2: Surface waviness and loads of the samples.

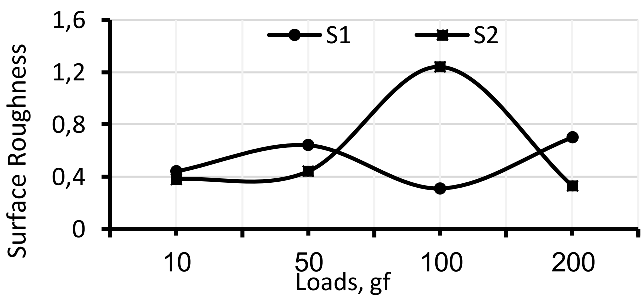


Figure 3: Surface roughness versus loads of samples.

Sample 2

The optical image of the indented alloyed soft martial (Sn-3.8-Ag-0.7 Cu) was obtained from sample 2 at a resolution of 200 µm using IFM, as shown in Figure 1b. The result obtained from Figure 1b is as shown in Table 1. The average depth of the diamond indentation is 101.6 µm, while the average diameter at which the indentation was conducted is 123 mm. The average surface roughness of the sample is 30.16, while the average surface

roughness profile is 13.9. The illustration shown in Figure 2 revealed that the surface waviness profile tends to flatten along a decreasing slope as more load is added.

Table 1: Surface waviness and roughness of the studied samples

Sample	Parameter	D-1	D-2	D-3	D-4	Average
1	*Depth (µm)*	11.02	6.24	2.06	6.135	6.36
	Diameter Surface (mm)	170	125	132.5	160	147.0
	Roughness	0.57	0.40	131.5	0.32	33.1
	Waviness	1.54	1.61	422	1.50	106.6
2	*Depth (µm)*	103.4	98.6	101.7	102.8	101.6
	Diameter Surface (mm)	115.5	132.5	121.5	122.5	123
	Roughness	7.73	103	4.93	4.61	30.16
	Waviness	17.7	14.62	13.44	10.02	13.9

D= Diamond

The deformation that is plastic in nature diminishes as more loads are added to the sample. For the surface roughness profile of sample 2, shown in Figure 3, the sample regains its elasticity after being subjected to different load conditions within 200 gf. The elastic peak of the surface roughness profile of sample 2 is highest at a load of 50 gf and is at its minimum at a load of 125 gf. Such elastic deformation is not present in the surface waviness profile of the sample. However, it can be surmised that the surface waviness profile of sample 2 underwent plastic deformation while the surface roughness was elastically deformed with respect to the increase in load.

The average values obtained from the two samples that were investigated are shown in Table 2. The values were limited to the depth, diameter, surface roughness, and surface waviness of the alloyed soft material (Sn-3.8 Ag-0.7 Cu). The average indent depth and sample diameter values of the samples did not affect the surface roughness and waviness values obtained from the hardness test since there is no consistent increase or decrease in the values.

Table 2 Summary of the average values obtained from the tow sample

Parameter	Average 1	Average 2

Depth ((*μm*)	6.36	101.6
Diameter*(mm)*	147.0	123
Surface Roughness	33.1	30.16
Surface Waviness	106.6	13.9

Conclusion:

In conclusion, this study utilized stereological methods to evaluate and analyze the surface parameters of soft materials. The identified stereometric parameters for dented surfaces included surface roughness, waviness, surface profile, and bearing ratio. The results demonstrated that when subjected to a certain amount of force under the influence of a load, soft materials possess an elastic property unless they are deformed. Additionally, our findings revealed that the waviness parameter is a crucial surface parameter in describing soft materials like Sn-0.7Cn solder. Moreover, the investigated soft material, Sn-3.8 Ag-0.7Cu, offered suitable techniques that could be extrapolated to a broader range of applications. It is worth noting that, despite careful production processes, the occurrence of microscopically small particles is unavoidable. Therefore, we highly recommend conducting thorough examinations of surface parameters such as surface roughness and waviness in industries, as they are responsible for determining the surface texture of materials. To enhance this method further and address any uncertainties associated with the surface of soft materials, we suggest testing the samples against brittle, ductile substrate systems with varying thicknesses and material properties. This would provide valuable insights and assurance for implementing these techniques effectively.

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