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MICROSTRUCTURAL CHANGES WITH SELECTED EXTRUSION VARIABLES IN PLASTIC DEFORMATION OF COMPLEX-SHAPED LEAD ALLOY

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Abstract

This paper investigates the effects of changing die land length and web to flange ratio on the pressure and surface structures of cold plastic deformation of a triangular-, T- and L-shaped lead alloy. There is a dearth of knowledge on the influence of die land length and web to flange ratio on microstructures of extrudates and as a result the impact of these parameters has not been fully understood in die design. The work, which is purely experimental model, was carried out on a 600KN Denison Universal hydraulic testing machine. The test specimens were extruded into triangular, T- and L-shaped sections from initially circular billets at varying die land length and web to flange ratio. A forward extrusion rig is designed and manufactured for the purpose of experimental investigation. The experimental results, for all the geometries investigated, showed that extrusion pressure, product quality and straightness increases with increasing die land length. The extruded sections were examined by optical metallurgical microscope (OMM) and the effects of die land length is seen to indicate obvious changes in grain morphology from initially coarse grains at 2.5mm die land length to very fine grains structure at die land length of 12.5 mm in the extrusion of triangular section. Hence, the microstructure changes observed shows that increasing die land length leads to profound refinement of grain and inclusions in lead alloy. For increasing web to flange ratio in the extrusion of L- and T-shaped lead alloy, there is increasing fairly uniform and fine-grain structure. However, there seem to be better grain refinement in T-shaped section than that of L-shaped section for the same web to flange ratio, this is probably due to geometrical differences.

Key words: die land, extrusion pressure, triangular- and l-shaped, grain refinement, lead alloy, microstructure

1. INTRODUCTION

Extrusion is a versatile metal forming operation because of its flexibility of production of range of geometry. A variety of shaped sections both simple and complicated, including many with re-entrant angles, are cold extruded in a rapid and economical manner and with high dimensional accuracy. Such shapes include extrusions of rectangular, hexagonal, I-section, T-section from circular billets in ferrous and non-ferrous metals. In recent years, however, some attentions have been devoted by some researchers in this field on investigating experimentally and theoretically the extrusion pressure of shaped sections before using upper bound method [1,2]. Further investigation on the deformation modes and the internal flow patterns of the deformed specimens are examined in detail so as to ascertain the metal flows in the production of shaped sections such as I and T sections [3]. From their investigations, it was found that for any given reduction in area of the I-shaped section, the extrusion pressure was greater when extruded from circular billets than when from square billets. Using an upper bound, a study has also been conducted to investigate the effects of die reductions, billet shapes, die opening geometrical shapes and surface conditions and dimensional ratios of rectangular die openings on the extrusion pressure of forward extrusion process [4]. In another investigation [5], the analysis of the extrusion pressure by the upper bound method was extended to the evaluations of extrusion pressures to complex extruded sections such as square, rectangular, I, and T shaped sections with power of deformation due to ironing effect at the die land taken into account. The extrusion pressure contributions due to the die land evaluated theoretically for shaped sections considered are found to increase with die land lengths for any given percentage reduction and also increase with increasing percentage die reductions at any given die land length. The effect of die land lengths on the extrusion pressure increases with increasing complexity of die openings geometry with I-shaped section giving the highest extrusion pressure followed by T-shaped section, rectangular, circular shaped die openings with square section die opening, giving the least extrusion pressure for any given die reduction at any given die land lengths. Kopp et al [6], showed that the total extrusion load measured when extrusion tests were carried out on simple shapes (circle, square, and rectangles with different length/ breadth ratios) are the sum of deformation and frictional loads. The frictional load was discovered to be virtually independent of the section shape. Ulysee [7] proposed that one of the ways to correct or control the metal flow in extrusion dies is by altering the die bearing length or the depth of the die opening.

In the present experimental paper, the effects of changing die land length and web to flange ratio on the pressure and Microstructural changes of cold plastic deformation of a triangular-, T- and L-shaped lead alloy were investigated to underscore the importance or otherwise of these parameters.

2. EXPERIMENTAL METHODS

2.1. Materials preparation and equipment used

An experimental setup was manufactured for the forward extrusion of triangular-, T- and L-shaped sections section from round billets, the setup being installed in a 600 ton universal testing machine. The split dies used for the case of triangular-, T- and L-shaped is seen in figure 1 with the arrow pointing to the position of die land length.

Lead alloy of approximate percentage compositions of Pb (84.6%), Sn (5.35%), Sb (8.13%), Cu (0.7%), As (0.25%), Bi (0.10%), Zn (0.005%), Al (0.005%), Cd (0.05%) was used for the tests. The sand cast billets were machined to a size slightly smaller than that of the container for smooth insertion of the billet into the container. The cast lead alloys of dimensions 30 mm in diameter produced were machined into smaller lead alloy specimens of dimensions 25.0 mm in diameter by 26 mm in height. Concentric grooves were made on the diametric ends of each work piece, so as to facilitate the retention of lubricant during testing.

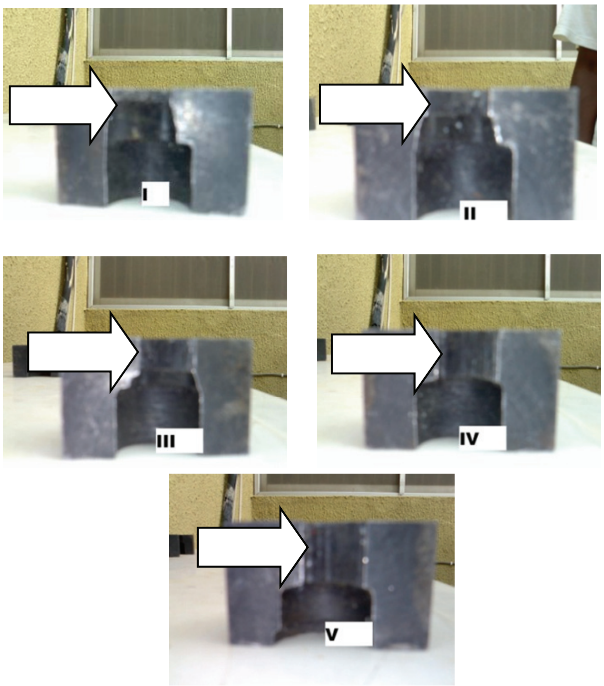


Fig. 1. Shows the photograph of split dies revealing the position and the varying length of the die land length.

2.2. Compression tests:

Compression and extrusion tests were carried out on a 600KN Denison universal hydraulic testing machine, using the extrusion and compression rigs positioned centrally on the machine. Lead alloy work pieces of 25.0 mm in diameter and 26 mm in height were used to obtain true stress– true strain data for the experimental evaluation of mean yield stress, σ, of the lead.

The procedure used for the compression test involved lubrication of the ends of the specimens with shear butter, so that the lubricant was allowed to retain in the grooves. The test specimen was centralized between the marked platens of the compression rig before load was applied. Tests were carried out at the strain rate of about $8.3 \cdot 10^{-4}$ s^{-1}. A suitably positioned dial gauge indicator was used to register the reductions in height of the test specimen and the corresponding load readings were also taken.

Load readings were recorded after each 0.50 mm travel of the cross head, until the final height of the compressed specimen was about 12.30 mm.

2.3. Extrusion tests

The container walls, dies, punch and specimens were first cleaned with methylated spirit solution to remove any grease from them, and were lubricated with shear butter for each test. The die was carefully placed in the recess of the die holder, to ensure that the die was symmetrically positioned within the die holder. The extrusion rig was carefully assembled together and then centralized on the hydraulic press. Load readings were taken at every 0.50mm of punch travel, as indicated by the dial gauge indicator. The maximum extrusion loads, for each extrusion test were determined and recorded, from which the extrusion pressure were calculated as the maximum extrusion load divided by the original cross-sectional area of the work piece.

Extrusion tests, as in compression test, were conducted at a strain rate of $8.3 \cdot 10^{-4}$ s^{-1}. Extrusion tests were continued, until the dial indicator's maximum range was reached within the steady stage of extrusion process.

After the end of each extrusion test, the die holder was disassembled out and the split dies were opened to remove the extruded product. The whole procedures were repeated using dies of various die land lengths for a given die reduction ratio of 81%.

2.4. Mechanical properties tests of extruded products

The degree of deflection or bend parameter is determined using venire height gauge at a uniform interval along the length of the extrudates. The bend parameter for each extruded product with different die land length were determined and recorded.

2.5. Microstructural tests of extruded products

Test samples were slowly cut with a hacksaw and ground on a rotating grinding machine while maintaining a steady flow of cooling water to prevent heat-induced modification of the microstructure. Various grades of emery paper (220, 320, 400 and 600) were used until a fine surface finish was produced. Polishing was done on a rotating polishing machine using diamond paste.

The specimens were then washed with cold water and immersed in methylated spirit for 2 minutes to eliminate any stains that might be left by the polishing compounds, futons of grease or dirt.

The specimens were then cooled in running water, dipped in a mixture of acetic acid (16.66%), nitric acid (16.66%) and glycerol (66.67%) and agitated vigorously for 6 minutes. The samples were then quickly transferred to running water to wash away the etchant.

The samples were then dried and examined in CETI optical metallurgical microscope.

3. RESULTS AND DISCUSSION

3.1. True stress-true strain curve

Figure 2 shows the true stress–true strain curve, frequently called a flow curve because it gives the stress required to cause the metal to flow plastically to any given strain, for lead tested at a strain rate of 8.3 x 10^{-4} s^{-1}.

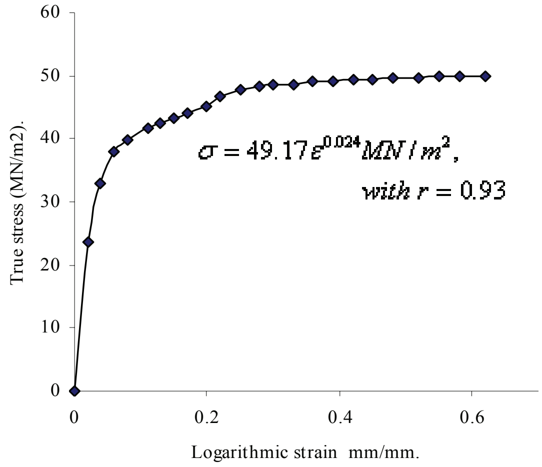


Fig. 2. True stress-true strain curve for lead alloy at strain rate of 8.3 x 10^{-4} s^{-1}.

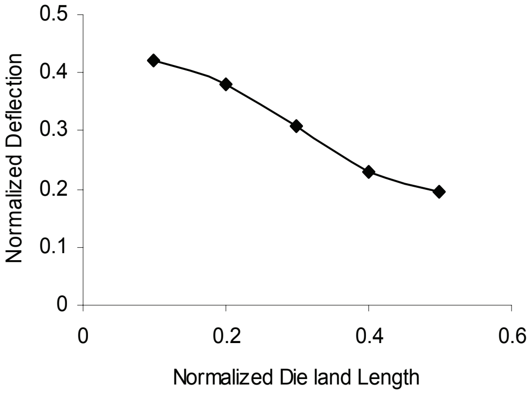


Fig. 3. Effects of increasing die land length on the deflection of extruded product.

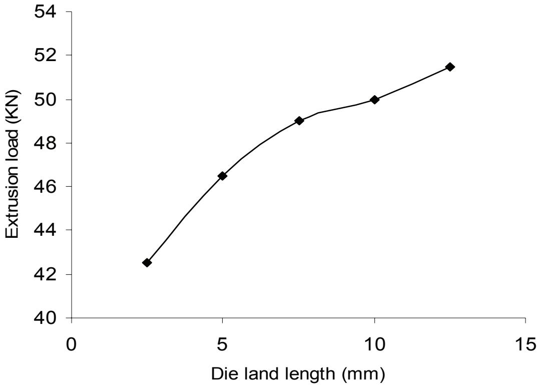


Fig. 4. Effects of varying die land on the maximum extrusion load.

The mean yield stress, $\bar{\sigma}$ for lead was calculated by averaging the yield stress over logarithmic strain, ε, corresponding to the reduction in area of the extrusion die used. The value of the mean yield stress for lead is 49.17 MN/m^2 at 81% reduction. The stress-strain relationship obtained by curve fitting to the experimental data for lead, using the least square method, is $\sigma = 49.17\varepsilon^{0.024}$ MN/m^2 with coefficient of correlation r = 0.93. Because the accuracy of numerical analysis is very much dependent on the flow stress of material, this relationship fits very well for determining the flow stress of different lead alloys for the most common working temperature. Laue and Stenger [8] have given a complete review of experimental values of flow stress by many authors.

3.2. Effect of die land on extrusion pressure

The normalized bend parameter, δ/Ho versus normalized die land length, x/D$_o$ is shown plotted in figure 3 for a constant billet's original length of 26 mm. It is seen that, increase in the values of dimensional bend parameter, δ/Ho, for a given billet's original height is higher at smaller die land lengths than at higher die lands. It can be seen that the bend parameter decreases, as the die land length increases. Figure 4 shows the effect of die land length on the extrusion load, it can be seen that the extrusion load increases with increasing die land length for a fixed given friction factor, m, of 0.065 and area reduction of 81%. Figure 5 (a) and (b) show typical photographs of the products of the extruded triangular sections. While figure 5(a) reveals bent or curvature of products which are due to variation in frictional forces at the die land due to ironing effect, figure 5(b) shows the triangular shape or geometry of the extruded products. It is observed that bends or deflections of different degrees are noticed in the products depending on the length of die land. It is seen that increasing die land length leads to increasing straightness or reduction of curvature of the extruded products.

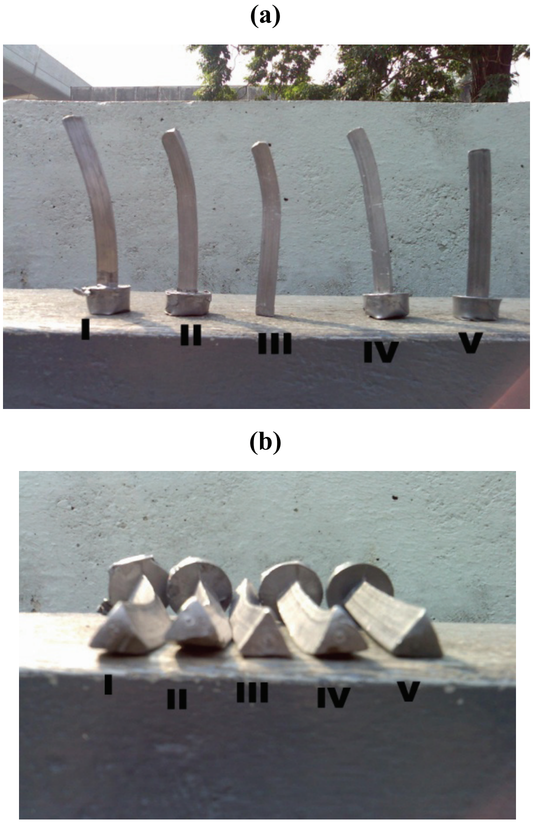


Fig. 5. Effect of die land length on the quality of the extruded equilateral triangular products.

Note: *For (a) & (b), the nominal value of die land are represented by: I = 2.5; II = 5.0; III = 7.5; IV = 10.0; and V = 12.5. All dimensions in mm*

3.3. Effect of die land length on the microstructure

Figures 6 and 7 show the effect of increasing die land length on the microstructural changes during the axisymmetric extrusion of triangular- and L-shaped lead alloy. The results indicate obvious change in grain morphology from initially coarse grains at 2.5 mm and 3 mm die land length respectively to very fine grains structure at die land length of 12.5 mm and 11 mm respectively. Optical metallurgical microscopy revealed a fairly uniform and fine-grain structure with increasing die land length. This shows that increasing plastic deformation or strain rate creates a subdivision of the initial grains into smaller crystallites separated by dislocation boundaries and gives rise to a preferred texture. This is as a result of increasing temperature of the extrudate with die land length as reported earlier [9]. It has also been reported [10] that grain subdivision is a function of different temperatures and alloying content.

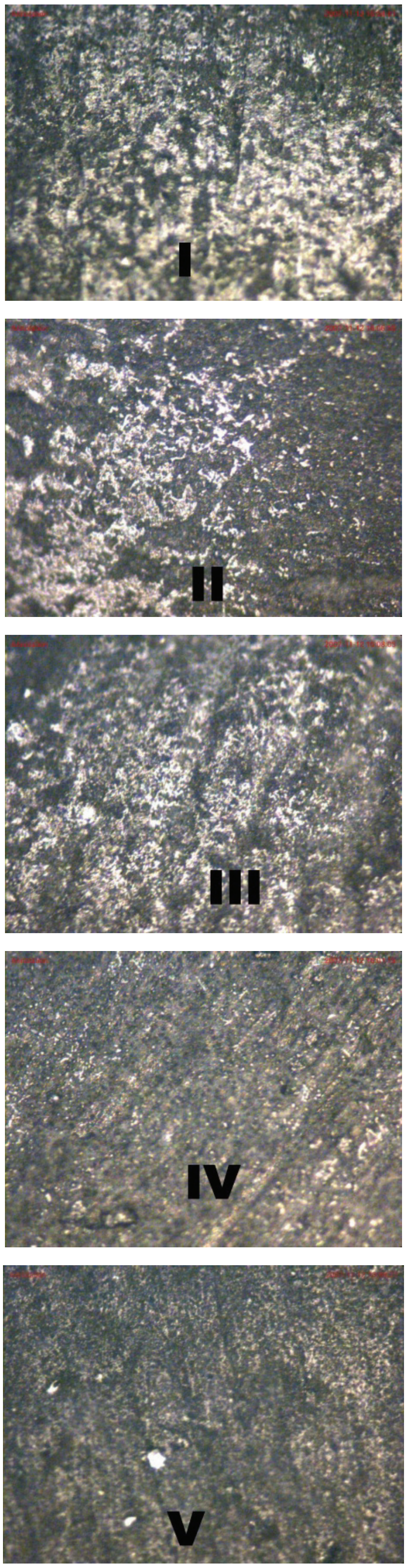
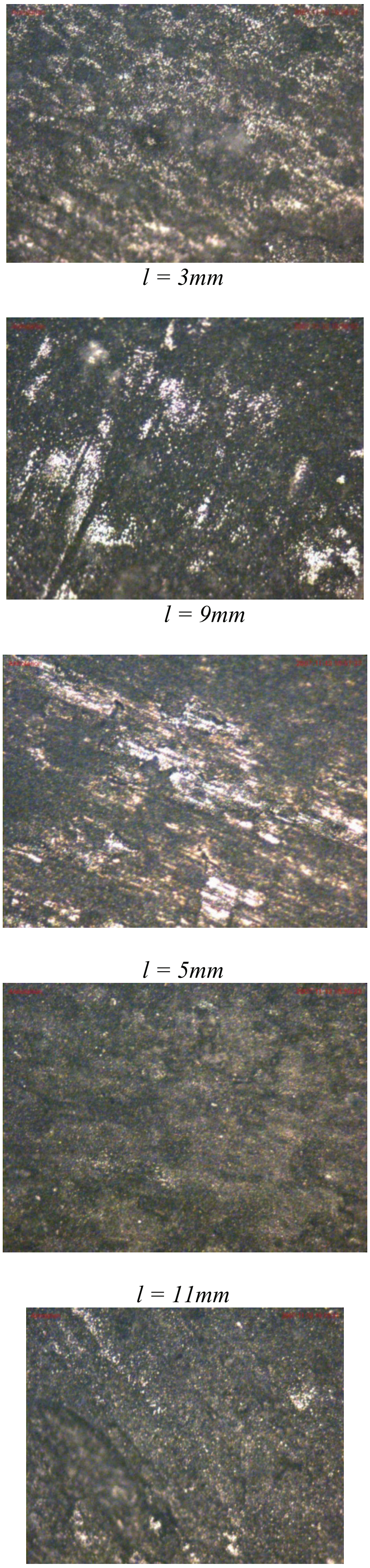


Fig. 6. *Effect of increasing die land length on the microstructure of lead alloy in the extrusion of triangular-shaped section.*

Note: *The nominal value of die land length are represented by: I = 2.5; II = 5.0; III = 7.5; IV = 10.0; and V = 12.5. All dimensions in mm*



l = 3mm

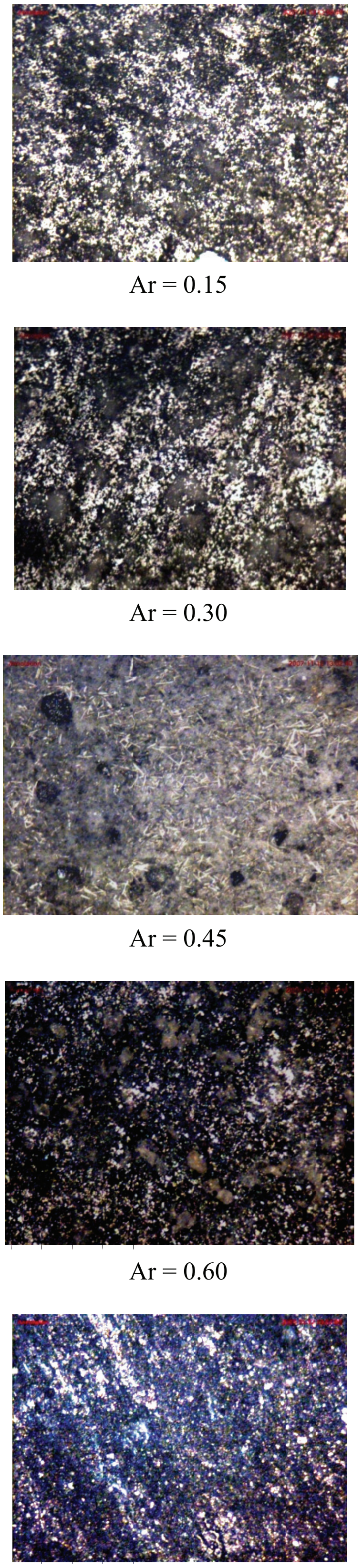
l = 9mm

l = 5mm

l = 11mm

l = 7mm

Fig. 7. *Effect of increasing die land length on the surface structure of extruded L-shaped lead alloy.*



Ar = 0.15

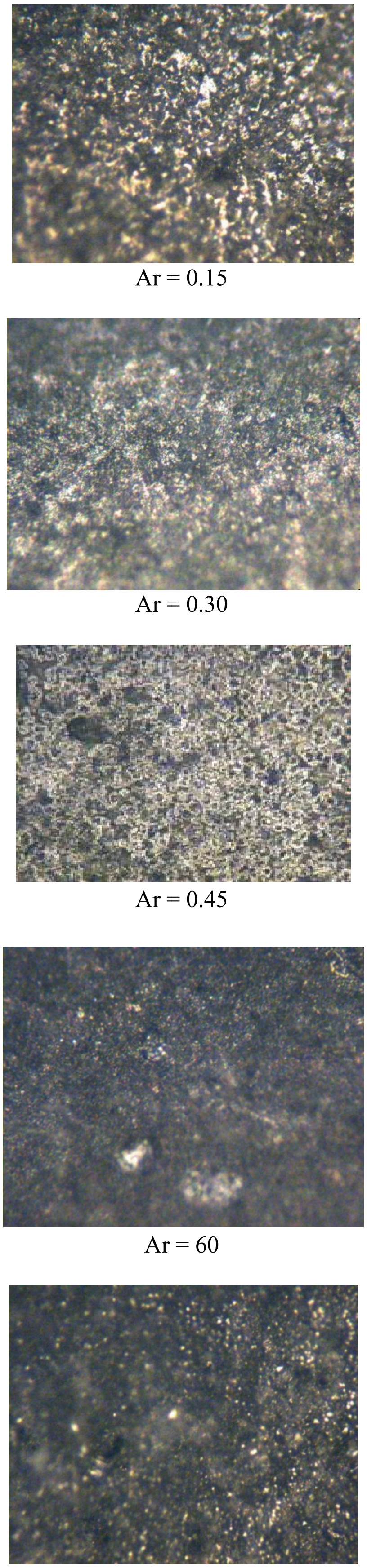
Ar = 0.30

Ar = 0.45

Ar = 0.60

Ar = 0.75

Fig. 8. *Effect of increasing area ratio on the surface structure of lead alloy in the extrusion of L-shaped section.*



Ar = 0.15

Ar = 0.30

Ar = 0.45

Ar = 60

Ar = 0.75

Fig. 9. *Effect of increasing web to flange ratio on the surface microstructure of lead alloy in the extrusion of T-shaped section.*

3.4. Effect of area ratio on the microstructure

Figures 8 and 9 show the effect of web to flange ratio on the microstructure of lead alloy in the extrusion of L- and T-shaped section respectively. For area ratio of 0.15, fairly coarse, non-uniform presences of second phase particles are revealed in both geometries. The copper bearing lead section through wall of cable sheath showing intergranular cracks that resulted from creep. The grains are of different sizes, possibly because of different grain refinement due to geometrical differences. Light-grey lead rich grains with dark- grey tin precipitates in grain boundaries and within grains. For area ratio of 0.3, less coarse, uniformly distributed second phase particles exist. It reveals the configuration of the lead dendrites and structure of the eutectic-like matrix of antimony-tin and lead. Again, that of T-section reveals better homogeneity than that of L-section. White particles of antimony-arsenic phase are of two types: small eutectic particles and large primary crystals are present. For area ratio of 0.45, there are some dark-grey lumps of tin seen on the L-shaped lead which is not so obvious in T-section. For area ratio of 0.60, these protuberances of dark-grey of tin were subdivided into smaller particles which shows a better refinement and hence a preferred structure. White particles of antimony-tin in a dark matrix of lead-rich solid solution are also present. These are more visible in L-section than in T-section. For area ratio of 0.75, there is fine dispersion of second phase particles with a homogenous matrix of lead. Copper-bearing lead, section through wall of cable sheath that resulted from creep is observed. The L-section shows more lead-base babbitt liner, continuously cast on steel backing strip than that of T-section. Also present is the antimony arsenic phase (white) in dark matrix of lead rich solid solution

4. CONCLUSION

It is found, for triangular-shaped lead alloy, that increasing die land length leads to increasing extrusion pressure and hence profound grain refinements due to continuous subdivision of grain structure. It is, also, found that the product quality and straightness increases with increasing die land length. For increasing web to flange ratio in L- and T-shaped lead alloy, there is increasing fairly uniform and fine-grain structure. There seem to be better grain refinement in T-shaped section than that of L-shaped section for the same web to flange ratio, this is probably due to geometrical differences.

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REFERENCES

1. Kiuchi, M, Kishi, H, Ishikawa, M., Study of Non-symmetric Extrusion and Drawing, Proc. 22nd Int. Machine Tool Design and Research Conference, 1982, 523-532.
2. Kiuchi, M, Ishikawa, M., Study of asymmetric extrusion and drawing of tubes analysis of inclined wall-thickness distribution of tube, Proc. 22nd Int. Machine Tool Design and Research Conference, 1982, 361-175.
3. Chitkara, N.R, Adeyemi, M.B., Working pressure and deformation modes in forward extrusion of I and T shaped section from square slugs, Proc. 8th Int. Machine Tool Design and Research Conference, Imperial College of Science, London, 1977, 289-301.
4. Ajiboye, J. S, Adeyemi, M. B., Computer Modelling of the Effects of billets and extruded symmetric section shapes in forward extrusion, Nigerian Journal of Technical Education, 16 (1), 1999, 1-14.
5. Ajiboye, J S, Adeyemi, M B., Upper Bound Analysis for Extrusion at Various Die Land Lengths and Shaped Profiles, Int. J. of Mechanical Sciences, 49, 2007, 335-351
6. Kopp, R, Long, G, Haber, G, Voswinckel, G. Effect of section shape on extrusion load: extrusion of round and flat sections, Metal Technology, 10, 1983, 368-370.
7. Ulysee, P., Optimal extrusion die design to achieve flow balance, Int. J. Machine Tools & Manufacture, 39, 1999, 1047-1064.
8. Laue, K., Stenger, H., Extrusion, American Society of Metals, Metals Park, Ohio, 1981.
9. Ajiboye, J. S, Adeyemi, M B., Effects of extrusion variables on temperature distribution in axisymmetric extrusion process, Int. J. Mechanical Sciences, 50 (3), 2008, 522-537.
10. Hughes, D.A, Kassner, M.E, Stout, M.G, Vetrano, J.S., Metal Forming at the Center of Excellence for the Synthesis and Processing of Advanced Materials, Journal JOM, 50 (6), 1998, 16-21.

ZMIANY MIKROSTRUKTURY ZALEŻNE OD WYBRANYCH PARAMETRÓW WYCISKANIA PRZY ODKSZTAŁCANIU PLASTYCZNYM WYROBÓW ZE STOPÓW OŁOWIU O ZŁOŻONYM KSZTAŁCIE

Streszczenie

Artykuł dotyczy wpływu zmian długości powierzchni styku matrycy i współczynnika kształtu (stosunek wymiaru środnika do stopki) do na ciśnienie i strukturę powierzchni stopu ołowiu po plastycznym odkształcaniu na zimno do kształtu liter T oraz L. Wiedza na temat wpływu długości powierzchni styku matrycy i współczynnik kształtu na mikrostrukturę wyciskanego wyrobu jest niedostateczna i w rezultacie wpływ tych parametrów na etapie projektowania matrycy nie jest w pełni zrozumiały. Praca, która jest jedynie modelem doświadczalnym, jest

prowadzona na hydraulicznej maszynie testującej 600KN Denison Universal. Próbki testowe zostały wytłoczone matryc o kształcie liter T oraz L z postaci okrągłej przy różnej długości styku powierzchni matrycy i współczynnika siatki kołnierza. Dalsze wytłaczanie jest zaplanowane w celu wykonania kolejnych badań eksperymentalnych. Wyniki, dla wszystkich badanych kształtów pokazały, że ciśnienie tłoczenia, jakość produktu i prostość rosną wraz ze wzrostem długości powierzchni styku matrycy. Wytłoczone fragmenty zostały zbadane za pomocą optycznego mikroskopu metalograficznego (OMM), a wpływ długości powierzchni styku matrycy wykazuje oczywiste wpływ na zmiany w morfologii ziaren od ziaren gruboziarnistych dla długości powierzchni styku matrycy równej 2.5 mm do drobnej struktury ziaren dla długości 12.5 mm. Zaobserwowane zmiany struktury pokazują, że wzrost długości powierzchni styku matrycy prowadzi do gruntownego rozdrobnienia ziaren i wtrąceń w stopach ołowiu. Przy rosnącym współczynniku siatki kołnierza w wytłaczaniu stopu ołowiu do kształtu liter T i L występuje spory wzrost jednolitych struktur ziarnistych. Jednakże we fragmentach o kształcie litery T występuje większa rozdrobnienie ziaren niż we fragmentach o kształcie litery L przy tym samym współczynniku siatki kołnierza, co prawdopodobnie jest efektem różnic geometrycznych.

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