AN INVESTIGATION INTO THE POSSIBILITY OF ROLL PEEN-FORMING: SOME EXPERIMENTAL RESULTS

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SUMMARY

A preliminary investigation was made to ascertain the possibility of roll peen-forming aluminium, copper and steel sheets in a two high mill, i.e. rolling them between a flat roll and a roll with a number of balls of \( \frac{1}{8} \) in. in diameter embedded around its curved surface at regular distances. The thickness of the sheet material varied (from 0.034 in. to 0.125 in.) as also did the width of the sheets. The pock-marked surface of the sheet was observed to form its convex surface and was harder than the base material. The curvature of the sheets reached a maximum with the greatest penetration. The characteristic features of the roll peen-forming process were studied and the effect of ball indentation on roll load, roll torque, radius of curvature of the product and the indentation shape.

NOMENCLATURE

- \( d_o \) diameter of the ball; diameter of indentation
- \( l_o, l \) original length of specimen, final length
- \( s \) distance between balls
- \( t_o, t \) original thickness; current thickness of sheet specimen
- \( t_1 \) current thickness of sheet specimen below indentation
- \( x, y \) co-ordinates shown in Fig. 11(b)
- \( P \) roll load
- \( p \) normal pressure on the ball
- \( T \) roll torque
- \( \Delta \) penetration
- \( \Delta/L \) specific penetration
- \( A \) projected area of ball indentations
- \( Y, Y_e \) yield stress; flow stress at \( \varepsilon = 0.1 \)
- \( P/Y_e \) non-dimensionalised value of specific pressure
- \( T/Y_e \) non-dimensionalised value of specific torque
- \( V_1, V_t \) peripheral speeds of the roll, Fig. 1(b)
- \( U_1, U_t \) horizontal components of peripheral speeds, Fig. 1(b)
- \( V, V_t \) vertical components of peripheral speeds, Fig. 1(b)
- \( n \) number of ball indentations across the sheet width

INTRODUCTION

It is well known that the shot-peening of a casting, a forging, or of a rolled product, results in an improved fatigue life of a product, see Plaster (1). Shot-peening introduces beneficial residual stresses and hardness variations in the product. The pock-marked surfaces formed due to the impact of the small spherical shots - the actions of which are similar to many small peen hammers - become harder than the base metal. If the material is thin, say a sheet material, it may also take up a curved shape due to the residual stresses created by the impact of the peen-shots. The curvature of the sheet material, however, remains a constant after a period of their application and would not increase even though the duration of shot peening may be increased a lot (2). The principle of shot-peen forming is well accepted for shaping sheet materials to attain precisely dimensioned curved shapes in aluminium and titanium sheets in a high technology industry such as Aerospace, see, for example, Fig. 1(a).

The object of the present preliminary investigation was to observe the effect of periodic ball indentation during the rolling of aluminium, copper and steel sheets when these are rolled between a flat roll and a roll with balls embedded around its surface with a view to exploring the possibility of subsequent adoption as a roll peen-forming operation, as distinct from the roll bending of plates (3) and the unsymmetrical rolling of sheets (4) that also produce curved shapes. The effect of periodic ball indentation under rotary motion conditions on the roll force, roll torque, radii of curvature of the product, the shape of the indentation of the sheet surface and the zones of plastic flow have been studied.

EXPERIMENTAL

Equipment

The two-high rolling mill used in the preliminary investigation was the same as that used earlier by Chitkara and Hardy (5) in their experiments on the I-section rolling of tellurium lead.

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The shaped rolls, earlier used in 1-section rolling, were replaced by a top flat roll and a bottom roll with balls embedded in it around its surface. A view of the rolls is shown in Fig. 2(a); the detailed dimensions of the rolls and the size and positions of the balls are shown in Fig. 2(b). The balls were \( \frac{1}{4} \) in. in diameter with only 0.088 in. of ball thickness sticking out from the surface; they were spaced \( \frac{1}{4} \) in. apart. The balls were embedded into the bottom roll surface carefully. At first, holes of suitable sizes were drilled in the roll surface using a milling machine and then each ball was force fitted into these holes. To hold the balls in position, specially designed caulking tools were employed to close the gaps around each ball which is in contact with the surrounding roll surface, see Fig. 2(a) (i). The surface of the top roll was turned so that its outermost radius was the same as the radius of the bottom roll measured from the top of each ball to the central axis of the bottom roll, so that there would not be any difference in the peripheral speeds of the two rolls.

Material and Specimens

In all, 11 sets of sheet specimens of three materials, aluminium, copper and steel, were rolled. Seven sets of tests were performed using commercially pure aluminium of different width to thickness ratios. In the first group, three sets of aluminium specimens were rolled and both the width and length of each specimen was kept constant at 2.6 in. (width) and 7 in. (length) respectively; the thicknesses of the sheet were 0.034 in., 0.0795 in. and 0.125 in. The next two sets of aluminium specimens had a constant thickness and length at 0.0795 in. and 7 in. respectively, but the width of the specimens was 2.2 in. and \( \frac{3}{16} \) in. Six more sets of specimens, each of 2.5 in. width, length 7 in. and thickness either \( t_0 = 0.0625 \) in. or 0.125 in., were prepared, two each of commercially pure aluminium, copper and steel. All the specimens were cut to size and their front, back and side edges machine.

Measurement of Roll Load

The load cells for the measurement of roll load during the rolling of copper, steel and aluminium sheets were the same as those used earlier by Chitkara and Taspinar (6) in their experiments on rolling blade pre-shapes. Typical responses from the two load cells during the rolling of an aluminium sheet 0.0795 in. in thickness, \( t_0 = \frac{3}{16} \) in. width, length 7 in. when rolled at a draught penetration \( \Delta = 0.05 \) in., are shown in Fig. 3(a) (ii).

Roll Torque Measurement

The torque meters used in the present investigation were also the same as in reference (6). Typical responses during the rolling of an aluminium specimen of original thickness \( t_0 = 0.0795 \) in., width \( W_0 = \frac{3}{16} \) in. and length \( l_0 = 7 \) in. at a draught penetration \( \Delta = 0.05 \) in., are shown in Figs. 3(a) (i) and 3(a) (ii).

Experimental Procedure

Before each test, the mill was kept running for about 10 minutes. This enabled the response from both the torque meters and the load cells to settle down. Seven sets of tests were performed using commercially pure aluminium specimens of different width to thickness ratios of the sheets and four sets, two each, were performed using copper and steel sheets. The details of these were given above. In all the tests the material was fed into the roll gap on an entry table, whose height was previously adjusted, with no entry guide. The draught penetration, \( \Delta \), were applied by adjusting the top screw-downs and using slip-gauges so that it caused the required penetration of the ball into the flat specimen when rolled. The penetration of the surface of the sheets was due only to these ball bearings; the flat surface of the bottom roll in which the balls were embedded was in contact with the specimen. The arrangement for rolling between two rolls, showing the relationship of draught penetration to thickness of the specimen is shown schematically in Fig. 3(b).

Stress-Strain Curves

True stress, \( \sigma \), versus logarithmic strain, \( \varepsilon \), curves from the tensile tests performed on the sheet material cut from the rolling directions of commercially pure aluminium, copper and steel are shown in Figs. 4(a), whilst the true stress, \( \sigma \), versus logarithmic strain, \( \varepsilon \), curve obtained from quasi-static compression tests performed on a small cylindrical specimen cut from the commercially pure aluminium of 0.125 in. thickness is shown in Fig. 4(a). The yield stress at a mean strain, \( \varepsilon \), of 0.1 was taken as 7.0 tonf/sq.in. for commercially pure aluminium, 12.3 tonf/sq.in. for copper and 18.3 tonf/sq.in. for mild steel.

RESULTS

Characteristic Roll Load and Torque Trace Outputs

The U.V. records of the output from the load cells and of the torque meters were made and typical records made in rolling an aluminium specimen, \( t_0 = 0.0795 \) in. at a draught penetration \( \Delta = 0.05 \) in. are shown in Fig. 3(a). It was observed that, in general, the peak load or peak torque would occur whenever the ball penetrated the sheet. Peak loads, however, also varied. It was later inferred that this probably depended on the number of balls that indented the surface at one time. In rolling sheets at the larger width of 2.6 in. and 2.5 in. it was observed that at a certain time, 4 balls were in contact with the sheet whilst, at other times, the number of balls, \( n \), indenting the material reduced to 3. The reason for this was the basic design arrangement of balls over the peripheral surface of the bottom roll, see Fig. 2(b), where the balls are fixed in a staggered fashion. Between the 4-ball and 3-ball penetration, the load response from the cells was observed to fall and then rise again for the next set of balls. Again, as only the bottom roll had ball bearings on its surface, the torque results for the top roll and for the bottom roll were observed to be different.