Development of a New Forming Process for Gun-Nail Heads By Simulation

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This paper describes how a model material technique has been applied in the analysis and development of a roll forming process for heading shanks, gun nails in particular. A commercial modelling wax "Filia" is extruded to the dimension of the model shank before the head is roll-formed by means of equipment designed for this process. The dependence of the roll diameter, of the velocity between the roll and the tool, and of the interface friction are shown for the model technique and compared with a theoretical estimate and with experimental results. A compound wax is used to study the proportion of virgin surface from the cropping in contact with the roll and the tool. A machine for production of gun nails was developed based on the model analysis. Experiments carried out with this machine confirm the results and the advantage of the model material technique.

INTRODUCTION

In cooperation between A/S Nordiske Kabe- log Traadfabriker, an industrial enterprise, and the Laboratory for Mechanical Processing of Materials at Technical University of Denmark, model technique has been employed in a project on the development of a machine for the production of gun nails.

Among the alternative production methods to the conventional forging process the roll process covering the production of a gun nail head from a drawn wire appeared to be attractive.

As shown in Fig. 1, the gun nails processed are characterized geometrically in that a circle section has been removed from the conventional circular nail head. This nail head design enables one to pack the nails closely because the nail shanks can bear against each other throughout the entire length of the nail.

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The nails are made of killed carbon steel of quality class III in DIN 17140 with the stress-strain curve shown in Fig. 2, obtained by uniaxial compression.

PROCESS DESCRIPTION

The wire is held with the necessary wire volume for the nail head outside the tool in which a cavity for the gun nail head has been formed.

In the production process the wire end outside the tool is bent towards the curved part of the cavity when making contact with the roll. Bending continues until the input angle has been reduced to some critical friction-dependent value in analogy with the angle of bite in normal rolling. After this flattening of the wire and the filling of the tool cavity will take place.

For this production method the principle of a continuously rotating machine can be employed, as shown in Fig. 3. The reduced nail head can be formed without a restraining raised shoulder at the straight edge of the tool cavity. Such a shoulder is used in the existing

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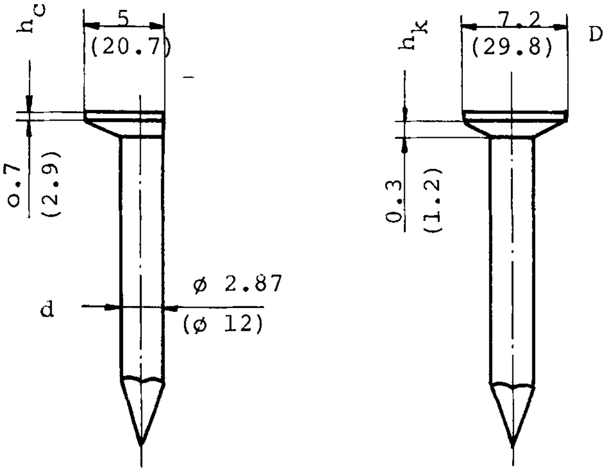

Fig. 1—Gunnail.

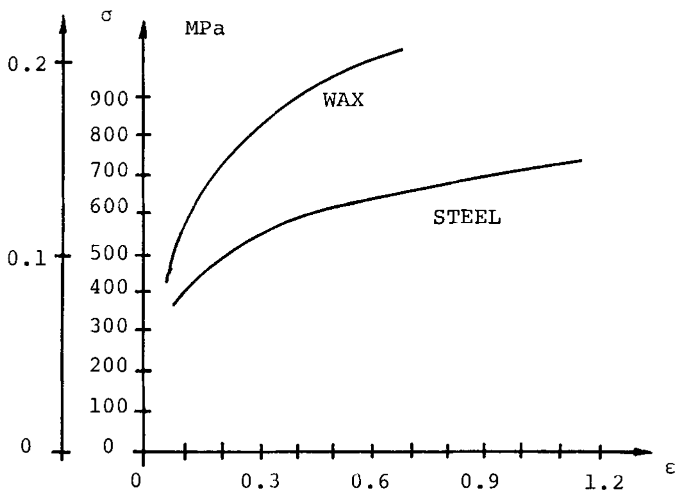

Fig. 2—Stress-strain curves for steel and model material.

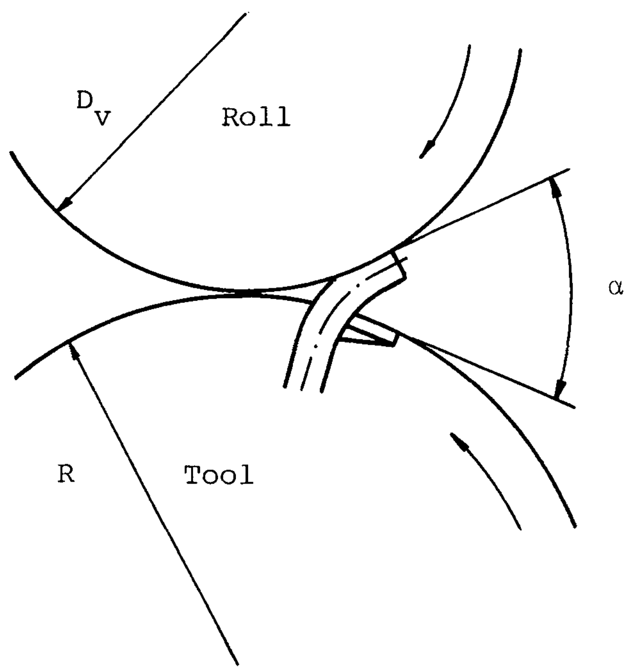

Fig. 3—Process.

production method based on forging in the axial direction, and burr produced at the straight edge of the nail head hampers nail assembly.

To obtain filling of the form cavity corners, a relative velocity between roll and tool is considered necessary so that the roll surface is moved towards the straight edge during the process. The important process parameters are thus considered to be the following: roll input angle—α, relative velocity—v_r, and friction and lubricating conditions.

THEORETICAL ESTIMATE

By using rolling theory, the material width as a function of the input angle at the process may be calculated if the input dimensions are known.

The input width b_1 is given by the wire diameter, and the input height h_1 may be determined by volume constancy:

$$h_1 = 0.76\frac{D^2 h_c}{d^2} + \frac{h_k}{3d^2}(D^2 + Dd + d^2)$$

The width is determined by the coefficient of spread:

$$\beta = \frac{b_2}{b_1} = \gamma^{-w} \quad \text{and} \quad w = 10^{a\xi^b\delta},$$

where

$$\gamma = \frac{h_{2m}}{h_1} = \text{the height reduction coefficient}$$

$$\xi = \frac{h_1}{D_v} = \text{the roll factor.}$$

$$\delta = \frac{b_1}{h_1} = \text{the form factor.}$$

a and b are material constants which according to Wusatowski[1] for the nail material used have been determined at -13.112 and 1.126, respectively.

The input angle α may be determined by

$$\cos\alpha = \frac{D_v(R - \Delta h) - h^2}{2R(D_v/2 + \Delta h)} \text{ and } \Delta h = h_1 - h_c - h_k$$

Using the nail dimensions employed, the calculations will produce the relation shown in Fig. 4 between the input angle and the coefficient of spread, from which it would appear that an input angle of 24° will produce sufficient spread. The use of this input angle calls for a friction coefficient μ of 0.45 in order that the rolling may be performed without prebending. The process

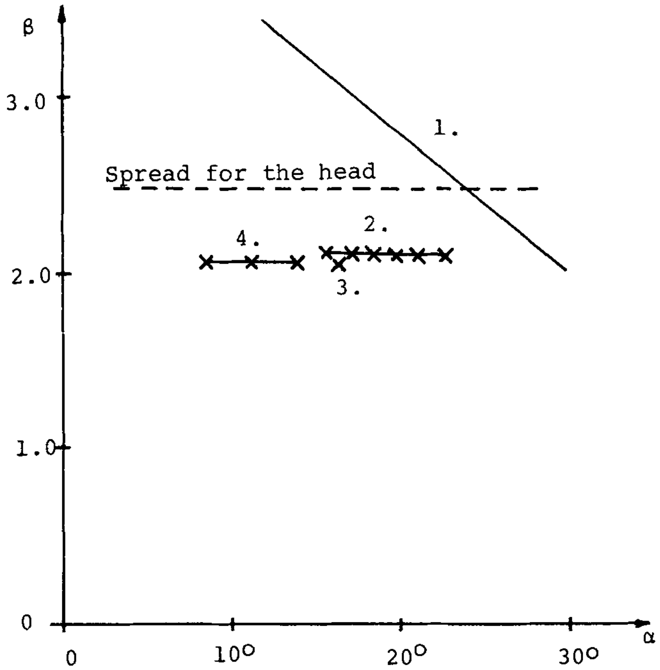

Fig. 4—Coefficient of spread as a function of input angle. 1. Theoretical estimate. 2. Experiments with model material, external rolling. 3. Experiment with steel, external rolling. 4. Experiments with steel, internal rolling.

will, therefore, depend on the friction conditions. In addition, the theory has been applied to a non-steady situation which is rather different from the rolling process.

EXPERIMENTAL ANALYSIS

The experimental analysis aims at clarifying deformation conditions and the influence of the various parameters on the process.

The experiments have been made by performing model tests where the nail material has been replaced by wax material. This reduces the forces required for the process, resulting in a simplification of the test equipment. At the same time, it permits an enlargement of the dimensions so that a visual assessment may be undertaken both during and after the deformation.

The wax used is the commercial material "Filia," which through studies[2–4] has been proven suitable for simulating metals since it is slightly strain-hardening with the stress-strain curve shown in Fig. 2.

The enlargement of the dimensions for the model tests is limited by the fact that the roll diameter has to be enlarged by the same scale factor. If the shank diameter is chosen to be 12 mm, the scale factor will be 4.138 and the other dimensions will be as shown in the brackets in Fig. 1.

The model equipment used is shown in Fig. 5. The outer dimensions of the equipment have been kept within reasonable limits by using roll sectors supported by a two-point bearing, permitting several roll diameters in the same equipment. The tool diameter is 1400 mm, and six rolls with different diameters (400, 472,

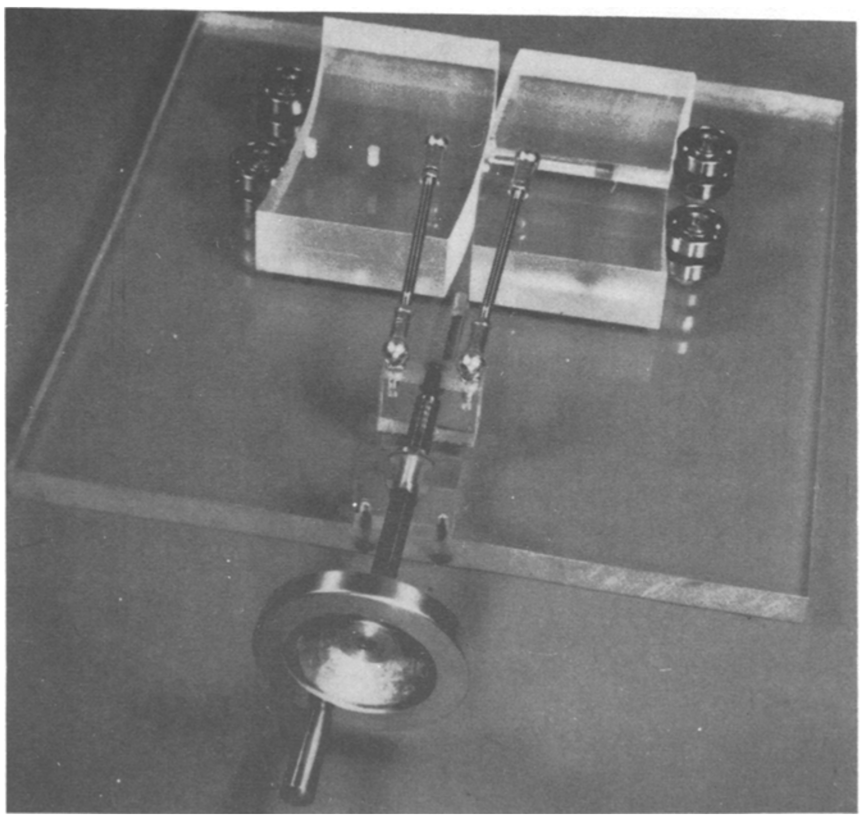

Fig. 5—Model equipment.

550, 622, 704, 1100 mm) are used so that the input angles indicated in Fig. 4 may be examined. It should be noted that the width has been calculated using the material constants for steel since they are unknown for wax.

The model equipment has been made in transparent acryl, chosen for the following reasons:

—This material is comparatively low-priced in the dimensions used.

—It is easy to process.

—The deformation may be observed through the tool and the roll during the process.

The relative velocity v_r between the roll and the tool is established by linking the tension rod at different radii.

The model tests are carried out to the following guidelines: A piece of extruded wax material having the nail shank dimension (diameter 12 mm) is cut off at a suitable length following which it is lubricated and placed in the tool with the calculated material length for forming of the head protruding over the tool cavity. This can be adjusted using a bottom screw. The tool and the roll having the diameter and lubricating conditions required are then mounted in the equipment, and the tension rods are mounted for the relative velocity chosen, and the test is performed.

THE INFLUENCE OF THE ROLL DIAMETER ON WIDTH

These tests were performed without a relative velocity and without any limitation in the tool cavity for a reduced gun nail head. Efforts were made to make friction conditions uniform by lubricating.

Test results are shown in Fig. 6, and in Fig. 4 the coefficient of spread is shown as a function of the input angle. It would appear from Fig. 4 that the input angle, and hence the roll diameter, has but little influence on the spread and thus on the natural filling of the tool cavity.

The explanation for this result may be that the nail shank will bend until the input angle is equal to the angle of bite for this roll process. In this case of uniform friction conditions and nail dimensions this is constant so that the true input angle will be constant regardless of the roll diameter.

RELATIVE VELOCITY AND FRICTION CONDITIONS

The tests concerning spread indicate further tests using roll diameters of 100 mm and 704 mm.

Test results for the two roll diameters are shown, with the parameters used, in Figs. 7 and 8. They show that relative velocity is necessary to obtain filling of the tool cavity corners, and that its size will be dependent on the friction conditions.

Two friction conditions have been used: no lubrication, and lubrication using a slip agent. This provides test conditions of high and low friction, respectively, between the roll and the material, considered to be the only realistic cases in the real process when using either a serrated or a smooth roll surface.

DEFORMATION OF THE WIRE SURFACE

The wire surface has a lubricant coating from the wire drawing process. This can be used when rolling the nail head so that direct lubrication may be omitted. To determine the movement of the wire surface during the roll process, black wax sticks with a thin red surface layer simulating the lubricant coating were manufactured.

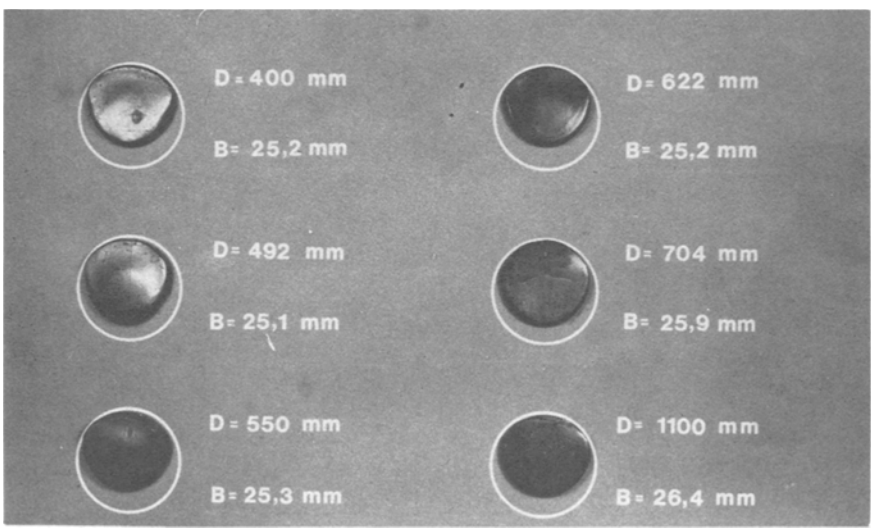

Fig. 6—Results from forming of the head with circular cavity and no relative velocity. Lubricant: Nat-Sil; Roll diam: D; Width of head: B.

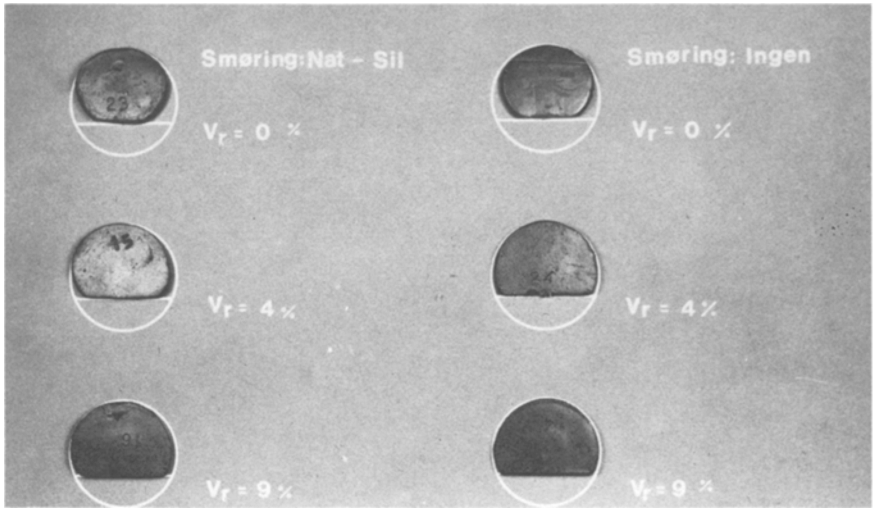

Fig. 7—Results from forming of the head with reduced cavity and varying relative velocity. Roll diam = 1100 mm. Left: Lubricated with Nat-Sil. Right: Unlubricated.

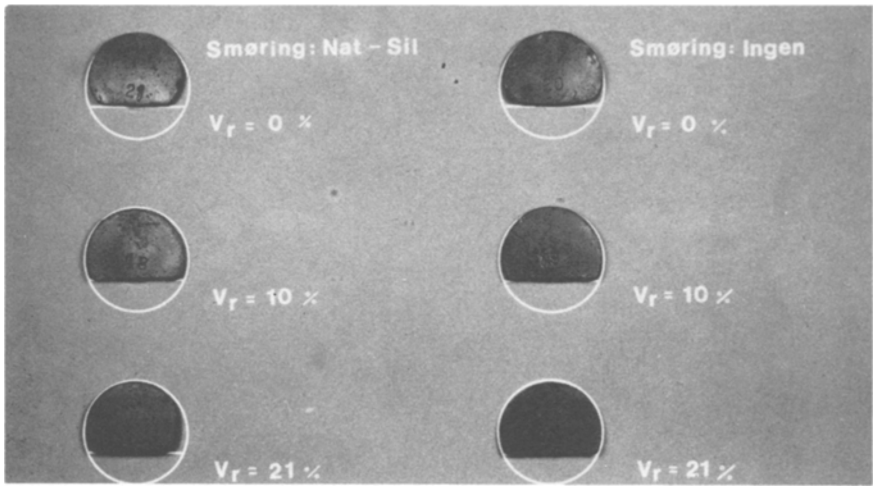

Fig. 8—Results from forming of the head with reduced cavity and varying relative velocity. Roll diam = 704 mm. Left: Lubricated with Nat-Sil. Right: Unlubricated.

Special simulating the lubricant coating were manufactured.

Special two-color wax sticks were produced by changing the extrusion from red to black wax. At a particular stage of the extrusion process, the black material is extruded out into the core while the red material is carried along on the surface from the dead zone behind the die. Using this method a homogeneous specimen is produced with a very thin and uniform surface layer. Figure 9 shows the undeformed specimen together with two rolled nail heads. One can see that the lubricant surface coating offers good protection during the process.

NAIL HEAD PROCESSING IN STEEL

Tests were performed using nail steel on a laboratory roll for discontinuous rolling,[5] in principle identical with the model equipment used.

This equipment does not permit a relative velocity between the tool and the roll, and the maximum attainable pre-stressing of the roll in comparison to the yield stress of the material used is less than that of the model equipment.

The laboratory roll could be used with the following parameters only:

$$D_v = 2R = 600 \text{ mm}$$

$$h_1 = 4.0 \text{ mm}$$

$$\alpha = 16.9 \text{ deg}$$

$$b_1 = 2.9 \text{ mm}$$

$$b_2 \text{ (theoretical)} = 8.8 \text{ mm}$$

The model equipment was adjusted using the corresponding parameters, and test results for steel and wax, respectively, are shown in Figs. 10 and 11.

These tests show good agreement between the two deformations and the need for relative velocity in order

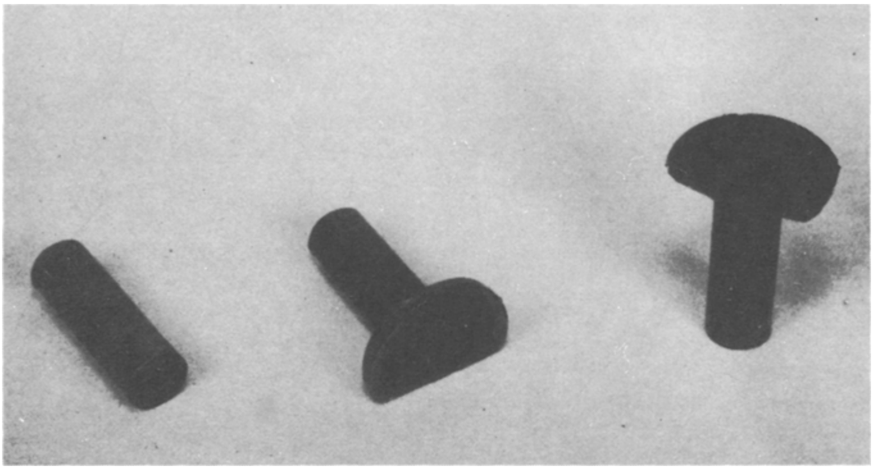

Fig. 9—Undeformed and deformed specimens of wax with surface layer.

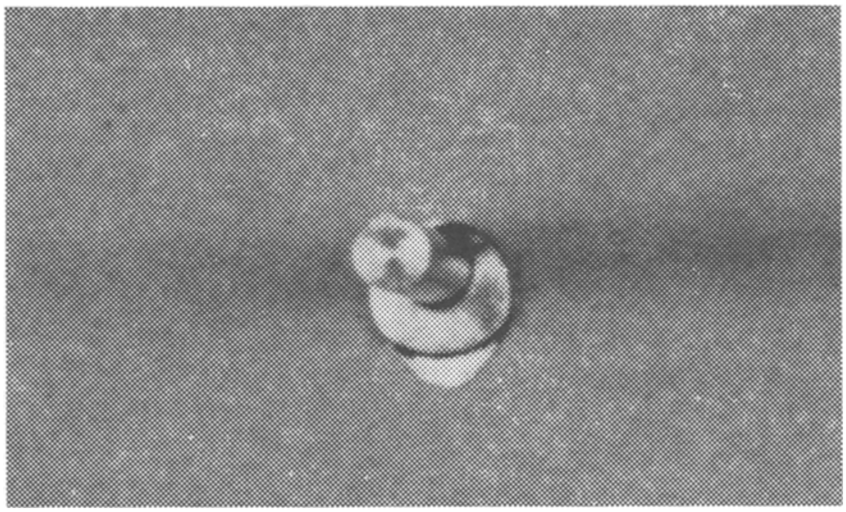

Fig. 10—Head in steel.

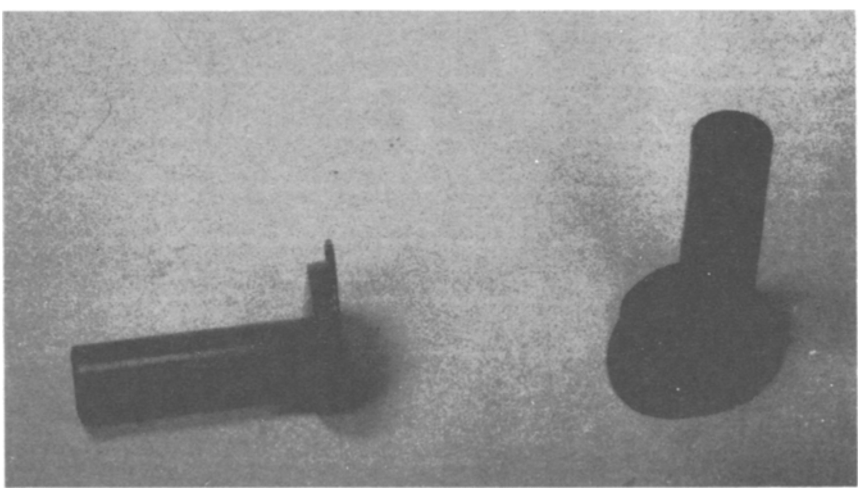

Fig. 11—Heads in wax.

to avoid burr formation on the curved part and to obtain filling of the corners.

PROTOTYPE MACHINE

On the basis of the process described above and the model tests performed for the production of gun nails by using a rolling process, a prototype machine for laboratory use was designed and built.

In this machine all forming is done by continuously rotating elements, including the forming of the point.

The application of rotating processes makes possible a relatively small, noiseless machine of high productivity, requiring little tool replacement.

In order to verify the indications of the model tests with respect to the small effect of the roll diameter on the spread, tests were performed using three different roll diameters without relative velocity. This produced results in agreement with the model tests, as shown in Fig. 4.

The roll diameter, however, influences the relative velocity required, which can be reduced when increasing the diameter. This is due to the fact that the time of deformation and thus the movement of the roll in relation to the tool increases with the diameter.

The process parameters for the production of the gun nail head were selected to be those below, when using a smooth roll:

$$\text{input angle } \alpha = 13 \text{ deg},$$

$$\text{relative velocity } v_r = 15 \text{ pct.}$$

This produced the desired gun-nail head using heavy pre-stressing between the roll and the tool to prevent burr formation on the straight edge of the nail head caused by the relative velocity.

CONCLUSION

The model material technique has been shown, by way of the tests made with wax material and steel, respectively, to be highly suitable for simulating a deformation process as highly complicated as the one described above for production of gun-nail heads and for determining the influence of the individual parameters on the process.

The wax model tests are comparatively simple to perform but one should pay due attention to every detail during the tests since what might seem a mere trifle may prove decisive in the real process. The forces required are small so that the results are very sensitive to apparently unimportant changes of conditions, furthermore the model equipment will frequently be more rigid than the equipment which will eventually be used for the process. Friction conditions are important to provide a true picture of the flow.

The model technique would seem to be a good alternative in comparison with theoretical and numerical methods. It may also provide a better knowledge of the process so that, for instance, a further theoretical analysis may be applied, closer to the conditions of reality.

NOMENCLATURE

a material constant
b material constant
b_1 input width
b_2 output width
D nail head diameter
D_v roll diameter
d wire diameter
h_1 input height
Δh decrease in height (absolute draft)
h_{2m} mean output height
h_c nail head height
h_k nail head cone height
R tool radius
v_r relative velocity
w spread exponent
α roll input angle
β coefficient of spread
δ form factor
ϵ strain
σ stress
ξ roll factor
γ height reduction coefficient
μ friction coefficient

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