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COMPRESSION OF BIMETALLIC COMPONENTS – ANALYTICAL AND EXPERIMENTAL INVESTIGATION

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ABSTRACT: *Present paper elaborates cold upsetting of dual-material component which consists of an outer ring and inner solid cylinder. Assembly is compressed by parallel flat dies. Outer ring is of mild steel C45 and inner core of softer C15 steel. Process has been analyzed analytically and experimentally. Analytical analysis was performed by slab method by introducing appropriate assumptions and boundary conditions. Two different analytical models have been considered. In the experimental work assembly of two different materials, outer ring (C45E) and inner cylinder (C15E), was compressed to different heights. During the process, forming load was recorded. Results have shown reasonable agreement between analytical prediction and experimental measurements.*
KEYWORDS: *Bimetallic Assembly, Upsetting, Forming load, Experiment*

INTRODUCTION

Upsetting of bimetallic workpieces in one operation is characterized by predominantly single compressive stresses between the two components which, as a result, give intimate contact and effective bound of the created assembly. This type of process could be described as an early manufacturing stage, prior to further forging. Also, coining of bimetallic coins (e.g. 2 € coin) is based upon this principle.

There has been relatively little published works on forging of two different materials in one operation. Investigation of bi-metallic compression, with the focus on the quality of the bond is presented in [1.]. Special attention has been paid to the contact between two components during upsetting. Process has been investigated experimentally and by numerical simulation. In [2.] authors examined the production of bi-metallic coins by compression of two circular components. They also checked the strength of the joint by measuring separating load. Upsetting of aluminium and copper billets at different heating conditions is described in [3.]. Authors had not detected separation of the interface between two components during upsetting process.

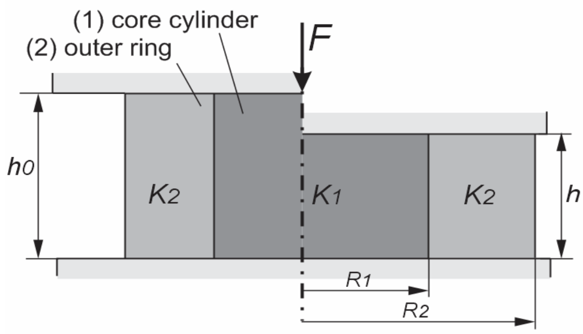

Figure 1. Compression of bimetallic components: at the beginning of the process (left) and during compression process (right)

Current paper elaborates analytical and experimental investigation of compression of dual-material component, which consists of cylindrical core of one material (1) and a hollow cylinder ring of another material (2) – Figure 1. Component was compressed by parallel flat dies. The aim of investigation was to compare theoretical calculations of loads with experimental values by imposing the same working conditions.

THEORETICAL APPROACH

Analytical analysis of upsetting of bi-metallic assembly in order to calculate upsetting load is carried out using slab method [4.], [5.]. Upsetting of inner cylinder and outer ring is analyzed separately respecting actual boundary condition.

Forming load was obtained by integration of normal stress over the contact surfaces. Two different combinations have been analyzed (Figure 2):

a) *Cylinder and ring are upset separately – Model M1*
b) *Cylinder/ring assembly is replaced (substituted) by cylinder with dimensions which are equal to the outer dimensions of the assembly (D x H) – Model M2. Stress – strain curve of this "replacing" cylinder is calculated as combination of K_1 and K_2, according to figure 2 and expression (3).*

Figure 2 presents two different model combinations for the calculation of upsetting load (Models M1 and M2).

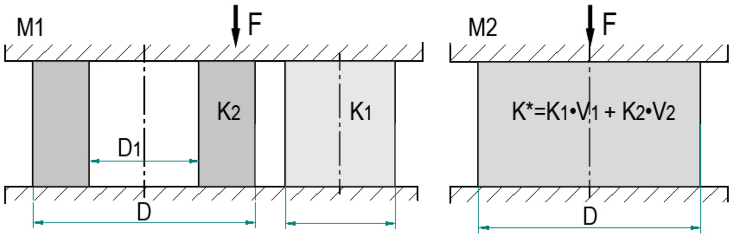

Figure 2. Schematics of two upsetting models

Model M1

In this case upsetting of two separate bodies – cylinder and ring – is analyzed. Load for cylindrical upsetting is:

$$F_{cylinder} = K_1 A_1 \left(1 + \frac{\mu}{3}\frac{D_1}{h}\right) \quad (1)$$

And for ring upsetting is:

$$F_{ring} = K_2 A_2 \left[1 + \frac{2\mu}{h}\left(R_2 - \frac{2}{3}\frac{R_1^2 + R_1 R_2 + R_2^2}{R_1 + R_2}\right)\right] \quad (2)$$

As cylinder and ring upsetting are classical examples which are elaborated in the relevant literature, derivation of both expression (1) and (2) is omitted here and can be found in [4.][5.][6.][7.].

Model M2

This model analyses upsetting process of cylinder with the dimensions which are equal to outer dimensions of the assembly (D x H). Effective stress of the cylinder material is combination of K_1 and K_2:

$$K^* = K_1 \cdot V_1 + K_2 \cdot V_2 \quad (3)$$

where V_1 – volume ratio of material (1) and V_2 – volume ratio of material (2)

Thus, K depends on volume ration between two materials, K_1 and K_2 in specific geometry case.*

Load is determined by:

$$F_{total} = K^* A \left(1 + \frac{\mu}{3}\frac{D}{h}\right) \quad (4)$$

Based upon presented analytical approach, maximum load at the end of the process has been calculated for four different cases (geometries) and for two different models (M1 and M2) of bi-metallic components. Table 1 provides info about geometrical data as well as calculated final loads. Model M1 was calculated using expressions (1), (2) and model M2 with (3), (4). Stress – strain curves for cylinder (K_1) and ring materials (K_2) are obtained in Rastegajev test and their form is:

$$K_1 = 276{,}44 + 397{,}715\varphi^{0{,}317}$$

$$K_2 = 289{,}68 + 668{,}78\varphi^{0{,}3184}$$

In analytical calculation friction coefficient of $\mu = 0.11$ was determined by using ring compression test [7.]. More about friction estimation can be found in [8.].

Table 1: Final loads calculated by theoretical analysis for four different initial geometries of specimens (Models M1 and M2)

Billet Nr.	Initial height h_0 [mm]	Total tool stroke [mm]	Initial diam. D_0 [mm]	Final height h [mm]	Log. def. φ	K_1 [N/mm²]	K_2 [N/mm²]	Calculated final load F_{uk} [kN]	
								Model M1	Model M2
1	60	23	40	37.00	0.48	592	820	1547	1580
2	60	28.1	40	31.90	0.63	620	867	1905	1955
3	40	18.76	40	21.24	0.63	620	867	1941	2017
4	14	5.85	40	8.15	0.54	603	839	1846	2013

EXPERIMENTAL WORK

In scope of experimental investigation bimetallic billets were compressed by flat tools of alloyed steel hardened to 63 HRC. Upsetting process was performed on 6.3 MN hydraulic press of high stiffness. As in theoretical approach, total of four different initial geometries of specimens were made. Table 2 contains geometrical details as well as the measured force at the end of the process for all four cases.

Table 2: Final loads obtained by experimental investigation

Billet Nr.	Initial height – h_0 [mm]	Total tool stroke [mm]	Initial diam. D_0 [mm]	Final height h [mm]	Log. def. φ	Measured final load [kN]
1	60.18	23	40	37.18	0.48	1475
2	60.14	28	40	32.14	0.63	1726
3	39.92	18	40	21.16	0.63	1869
4	14.20	5.9	40	8.3	0.54	1790

Exemplarily, in figures 3 and 4, photographs of initial and final workpieces as well as upsetting process are shown.

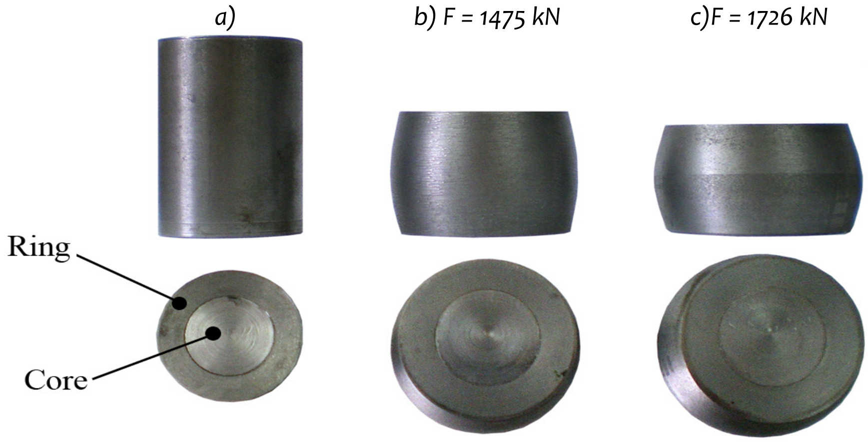

Figure 3. Photo of billets: a) billet Nr. 1 prior upsetting, b) billet Nr. 1 after upsetting, c) billet Nr. 2 after upsetting [7.]

Billets were deformed to the identical logarithmic deformation of height as in theoretical analysis, in order to enable direct comparison between calculated and experimental loads.

Figure 4. Experimental compression of bimetallic specimen [2.]

DISCUSSION WITH CONCLUDING REMARKS

This paper presents analytical and experimental investigation on bimetallic upsetting of cylinder and ring assembly. Ring and cylinder were made from two different steel materials with different flow-stress curves. Totals of four different upsetting cases were investigated both analytically and experimentally. In analytical calculations, final loads for billets upsetting were obtained by employing two different models (M1 and M2). Figure 5 presents maximal load values obtained analytically according to models M1and M2, as well as corresponding experimental maximal load for each upsetting case. As it can be seen from figure 5, experimental investigations correlate fairly well with results obtained by theoretical analysis.

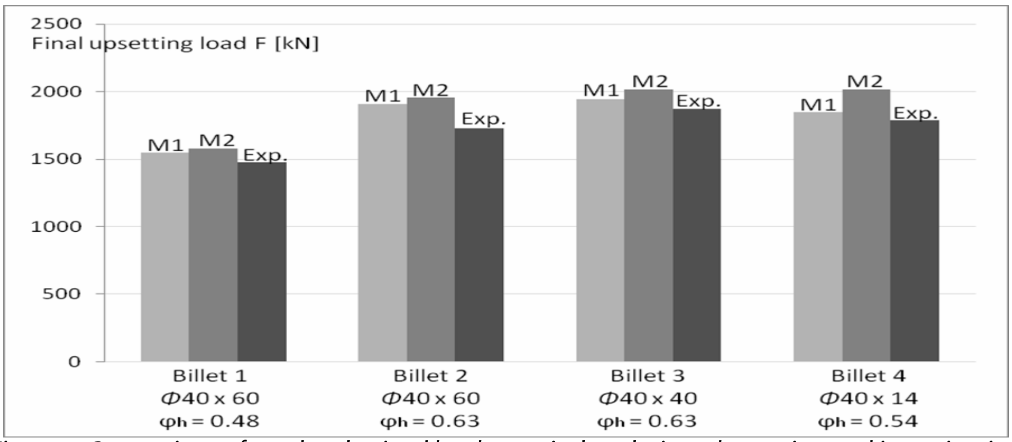

Figure 5. Comparison of results obtained by theoretical analysis and experimental investigation

It should be pointed out that in presented analytical solution friction between core cylinder and ring surface has not been taken into account, which inevitable reflects on the accuracy of the obtained results. Further improvement of the analytical solution should consider this aspect of the problem.

In order to gain to further relevant information related to current issue, numerical simulation by adequate software package should be conducted.

Also, as a valuable check of numerical and analytical solutions, more extensive experimental work is needed. Both these activities are planned in future work.

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