International Conference on Science, Engineering & Management Trends

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

Design Development, Sheet-Metal Forming Simulation and Progressive-Die Manufacturing Study of Hinges for Industrial Control Cabinets

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Abstract- Hinges control the alignment, opening behaviour and service life of industrial control cabinet doors, yet sheet-metal hinges must be formed without local failure on a production tool. This paper presents the design development, forming simulation and manufacturing study of two in-house sheet-metal hinge designs produced on a progressive die. Three-dimensional CAD models were used to build a multi-operation (OP10–OP30) forming model in STAMPACK, and the final-operation results of the hinge geometry for which complete outputs were available are evaluated through thinning, forming-limit (FLD) safety-zone and FLD map-centre contours. Closed-form relations for percentage thinning, true thickness strain, volume constancy and forming margin convert the displayed extremes into engineering quantities. The simulation predicts thickness changes between +1.92 % and −27.44 %, the largest thinning being confined to the root of the rolled knuckles; this corresponds to a thickness ratio of 0.726 and a true thickness strain of −0.321. The peak FLD map-centre value is 20.82 on a 0–100 scale, a margin of about 79 %, and no Fail or Risk zone is visible on the formed surface. The manufactured hinges were visually inspected; quantitative dimensional validation and springback measurement are identified as the principal future work.

Keywords- control cabinet hinge, sheet-metal forming, STAMPACK, progressive die, forming-limit diagram, thinning, finite element simulation.

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I. INTRODUCTION

Industrial control cabinets enclose electrical and automation equipment and rely on door hinges to provide controlled rotation, alignment and repeatable access. Sheet-metal hinges are economical for high volumes because the mounting flange, neck and rolled knuckles can be produced by cutting, bending and curling in a single progressive die. The same geometry, however, forces large local deformation at the knuckles, where excessive thinning, cracking or elastic recovery can compromise fit and strength.

Finite element (FE) forming simulation allows these risks to be examined before and during tool try-out and has become a standard tool in die development [1]–[3]. The reliability of the prediction depends on the material data, process definition and, above all, on how the result variables are interpreted.
This paper reports the design development, STAMPACK forming simulation and progressive-die manufacture of two in-house hinge designs for control cabinets. The contributions are: (i) a CAD–simulation–manufacture workflow for sheet-metal hinges; (ii) a set of closed-form relations that convert the displayed simulation extremes into thickness ratio, thickness strain, local area expansion and forming margin; and (iii) an evidence-limited assessment that states explicitly which conclusions the available data support.

Background
Sheet-metal forming converts a flat blank into a three-dimensional part by plastic deformation. In bending and curling, the outer fibres are stretched and the inner fibres compressed, so the strain distribution depends on bend radius, thickness, material and tool geometry. FE analysis represents this process by discretising the sheet and applying tool motion, contact and material models; shell and continuum formulations, geometric and material nonlinearity and error control are reviewed in [1], and solution procedures, element selection and yield criteria in [2]. Industrial adoption of forming simulation and the need to judge numerical predictions against practice are discussed in [3].

Formability is commonly assessed with the forming-limit diagram (FLD), which relates the principal strains at the onset of localised necking. The Marciniak–Kuczynski model and its developments are the main theoretical route to forming-limit curves and show how material and process factors shift the limits [4]. Thickness change is a complementary indicator: percentage thinning is derived from initial and final thickness at the same location, and its significance depends on the acceptance criterion used.

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Springback, the elastic recovery after tool release, controls the final geometry and is sensitive to both physical and numerical parameters [5]. For progressive-die parts, the sequence of operations affects die size, accuracy and cost [6]. STAMPACK is a forming-simulation package whose applications include prototype, progressive-die and transfer-die processes [7]. The present work applies these ideas to two specific hinge designs and documents what can and cannot be concluded from the available outputs.

II. METHODOLOGY

The study follows the sequence shown in Fig. 1: functional study of the two hinge designs, three-dimensional CAD modelling, preparation of the STAMPACK forming model, simulation, evaluation of results, manufacture on the progressive die, visual inspection and comparison.

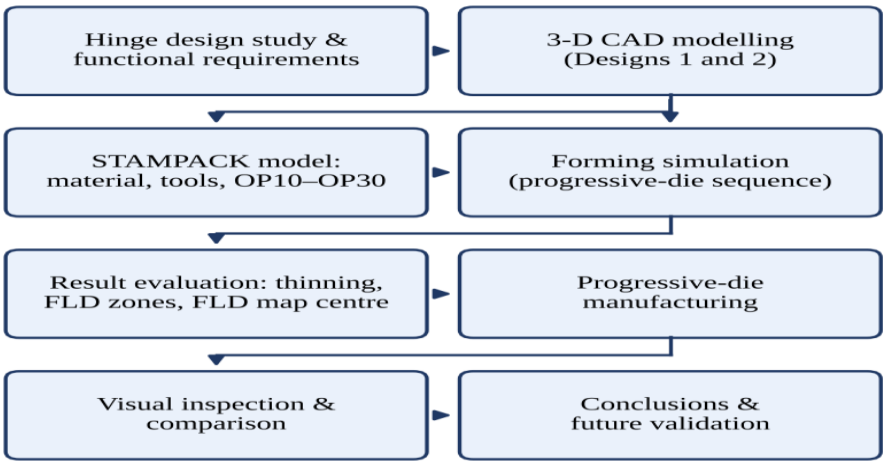


Fig. 1. Methodology flow of the design, simulation and manufacturing study.

1. Design and CAD Modelling

Each hinge consists of a mounting flange, a bent base, a narrow neck and two rolled knuckles that form the pivot (Fig. 2). The knuckles and the transition into the neck require the largest deformation and are therefore the regions of main interest. The CAD models provide the geometry for the forming model.

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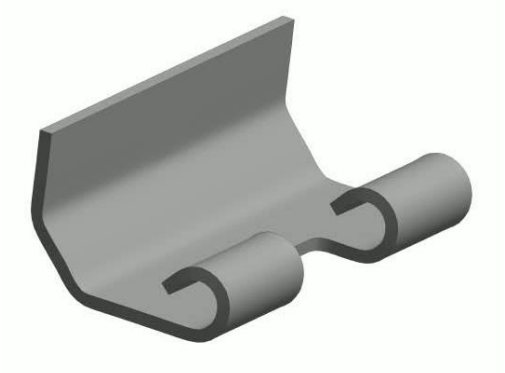


Fig. 2. Three-dimensional CAD model of the hinge (Design 1).

2. Forming Simulation

The forming process was modelled in STAMPACK as a sequence of operations labelled OP10, OP20 and OP30, representing the progressive-die forming stages. The results evaluated here are taken at the end of OP30 (remaining stroke 0.00 mm) and comprise the thinning (%) contour, the FLD safety-zone contour and the FLD map-centre contour.

3. Manufacture and Inspection

Both hinge designs were manufactured on an actual progressive die. The finished components were visually inspected for overall shape, formed features and visible forming-related irregularities. No dimensional measurement was performed, so the physical validation is qualitative.

III. MATERIAL AND MODEL DATA

The STAMPACK material database entry 1.0375-TS275 lists a yield strength of 267 MPa, a tensile strength of 390 MPa and a total elongation of 27.5 % (Table I). Other entries (CR1-UC-EG_DC01, FeP01_A) are present in the database, and a reference mark against St 37-2 was noted; neither establishes which material card was assigned to the hinge model, so the values are reported as database data pending confirmation. The FLD plot carries the forming-limit-curve label FLC_AC_2.0mm_N1, which suggests a 2.0 mm sheet; this value is used below only as an illustrative thickness.

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TABLE 1: MATERIAL DATABASE ENTRY AND MODEL IDENTIFIERS

Item	Value
Database entry	1.0375-TS275
Yield strength, σ_y	267 MPa
Tensile strength, σ_u	390 MPa
Total elongation	27.5 %
Forming-limit curve	FLC_AC_2.0mm_N1
Operations modelled	OP10, OP20, OP30
Result state evaluated	OP30, stroke 0.00 mm

IV. ANALYTICAL RELATIONS AND CALCULATIONS

1. Thickness Change

With initial sheet thickness t_0 and final thickness t_f at the same location, the percentage thickness change is

$$\Delta t = \frac{t_f - t_0}{t_0} \times 100 \qquad (1)$$

where, in the STAMPACK "Thinning (%)" legend, negative values denote thinning (red end of the scale, −20 %) and positive values denote thickening (blue end, +10 %). This sign convention is read from the legend and should be confirmed against the solver documentation. The final thickness follows from

$$t_f = t_0\left(1 + \frac{\Delta t}{100}\right) \qquad (2)$$

2. Strain and Area Expansion

The true thickness strain at a point is

$$\varepsilon_3 = ln\left(\frac{t_f}{t_0}\right) \qquad (3)$$

Because plastic deformation of metals is volume-preserving, the principal strains satisfy

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ISSN: 2348-4098, P-ISSN: 2395-4752

$$\varepsilon_1 + \varepsilon_2 + \varepsilon_3 = 0 \qquad (4)$$

so that the thickness strain fixes the sum of the in-plane strains. The corresponding local surface-area ratio is

$$\frac{A}{A_0} = \frac{t_0}{t_f} = e^{\varepsilon_1 + \varepsilon_2} \qquad (5)$$

3. Material Capacity and Forming Margin

The yield ratio indicates the available strain-hardening reserve,

$$YR = \frac{\sigma_y}{\sigma_u} \qquad (6)$$

and, if the FLD map-centre value *U* is interpreted as the percentage of the forming limit reached, the margin at the most heavily loaded point is

$$M_{FLD} = 100 - U_{max} \qquad (7)$$

4. Calculated Values

Substituting the displayed extremes (Δt_{min} = −27.4393 %, Δt_{max} = +1.9159 %, U_{max} = 20.8195) gives the values in Table II and Fig. 3. The minimum corresponds to a thickness ratio of 0.7256, a true thickness strain of −0.3207 and a local area expansion of 37.8 %. The displayed minimum exceeds the 20 % lower bound of the legend by a factor of 1.37, which is why the most strongly thinned zone appears saturated red.

Table 2: Calculated Quantities from the Simulation Extremes

Quantity	Relation	Value
Thickness ratio, minimum	Eq. (2), t_f/t_0	0.7256
Thickness ratio, maximum	Eq. (2), t_f/t_0	1.0192
Final thickness, minimum†	Eq. (2)	1.451 mm
Final thickness, maximum†	Eq. (2)	2.038 mm

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ISSN: 2348-4098, P-ISSN: 2395-4752

Quantity	Relation	Value
Thickness strain, minimum	Eq. (3)	−0.3207
Thickness strain, maximum	Eq. (3)	+0.0190
In-plane strain sum, $\varepsilon_1+\varepsilon_2$	Eq. (4)	0.3207
Local area ratio, A/A_0	Eq. (5)	1.378
Spread of thickness change	$\Delta t_{max} - \Delta t_{min}$	29.36 points
Yield ratio, YR	Eq. (6)	0.685
Forming margin, M_{FLD}	Eq. (7)	79.2 %

†Illustrative, assuming t_0 = 2.0 mm from the FLC label; multiply the ratios by the actual sheet thickness otherwise.

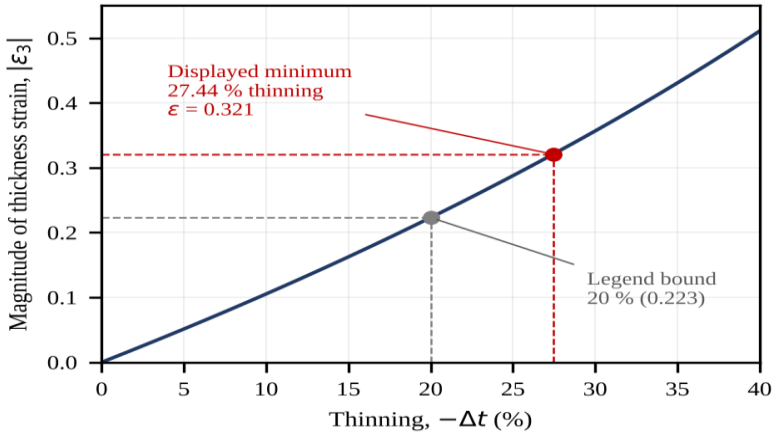


Fig. 3. True thickness strain versus percentage thinning from Eq. (3), with the displayed minimum and the legend bound marked.

V. RESULTS AND DISCUSSION

1. Forming Progression and Final Geometry

The OP10–OP30 sequence develops the flange, base bend, neck and the two rolled knuckles. The OP30 geometry in Figs. 4–6 shows the intended hinge profile fully formed in the model. No numerical

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ISSN: 2348-4098, P-ISSN: 2395-4752

geometry-deviation or springback output was available: the "FLD Map Center" values (20.82 and −0.007) are a forming-limit measure and must not be read as springback. Springback therefore remains a qualitative consideration [5].

2. Thickness Distribution

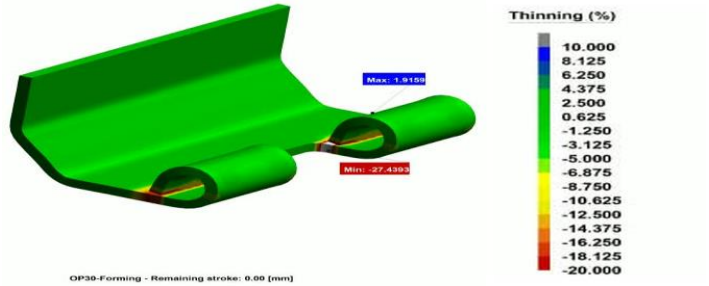


Fig. 4. Thinning (%) at the end of OP30; displayed extremes +1.9159 and −27.4393.

Most of the flange and base remain within a few percent of nominal thickness (green band of the legend). The displayed extremes are +1.9159 and −27.4393 (Fig. 4). The minimum, a thickness ratio of 0.726 by Eq. (2), is localised at the knuckle root where the curl closes onto the neck, which is consistent with the severe bending and contact there. The maximum thickening of 1.92 % is negligible by comparison. The large spread of 29.4 points between the extremes shows that thickness change is a highly local, not a global, feature of this hinge.

3. Forming-Limit Assessment

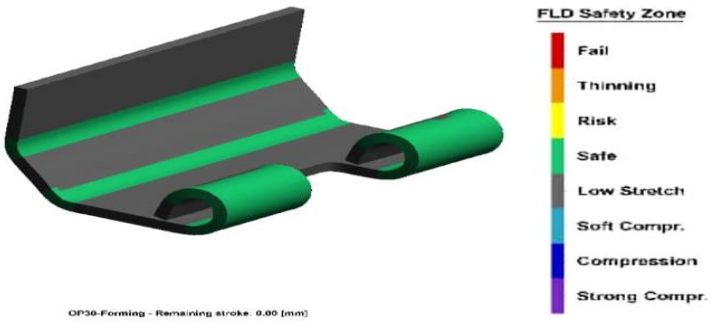


Fig. 5. FLD safety-zone contour at the end of OP30.

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In the safety-zone contour (Fig. 5) the flat flange and base are in the Low Stretch zone and the bend radii and knuckle bands are Safe. No Fail, Thinning or Risk zone is visible in this view. The contour should be read with care: the knuckle interior is not visible in the displayed orientation, and the FLD "Thinning" category is a strain-state class that is distinct from the percentage thinning in Fig. 4.

4. FLD Map Centre

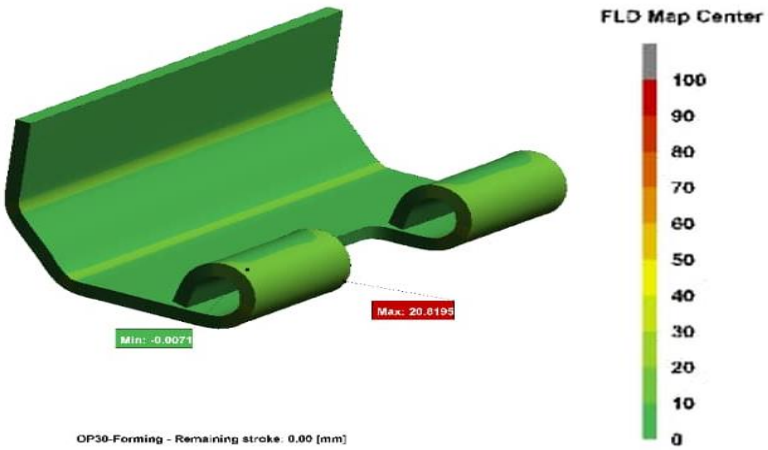


Fig. 6. FLD map-centre contour at the end of OP30; extremes 20.8195 and −0.0071.

The FLD map-centre contour (Fig. 6) has a peak of 20.82 on a 0–100 scale, located on a knuckle. If this variable is the fraction of the forming limit reached, the margin from Eq. (7) is 79.2 %, indicating that the strain state lies well inside the limit curve. The local thinning of 27.4 % is large relative to this utilisation, which suggests a concentrated edge or contact effect that a mid-surface forming-limit check does not capture. Extraction of the strain path at the node of minimum thickness is recommended to resolve this.

5. Manufacturing and Visual Inspection

Both hinge designs were produced on the progressive die, showing that the simulated forming sequence is practicable on the actual tooling. Visual inspection provides qualitative confirmation of the formed shape only; it does not establish dimensional accuracy, tolerance conformity or quantitative agreement with the simulation.

6. Limitations

- The material card assigned to the model and the 2.0 mm thickness require confirmation.
- Complete result sets were available for one hinge geometry (Design 1); a comparison with Design 2 is not made.
- The sign convention and definition of the thinning and map-centre variables are inferred from the legends.
- Springback and dimensional deviation were not evaluated, and the mapping of OP10–OP30 to physical die stations needs to be confirmed from the die layout.

VI. CONCLUSION AND FUTURE WORK

A CAD–simulation–manufacture workflow was applied to two in-house sheet-metal hinge designs for industrial control cabinets. For the geometry with complete results, STAMPACK predicts thickness changes from +1.92 % to −27.44 %, with the thinning confined to the knuckle root (thickness ratio 0.726, true thickness strain −0.321). The FLD map-centre peak of 20.82 gives a forming margin of about 79 %, and no Fail or Risk zone is visible on the formed surface. Both hinges were manufactured on the progressive die and visually inspected.

Future work should: confirm the material card and sheet thickness; extract the strain path at the minimum-thickness location; run the springback analysis; measure critical dimensions, bend angles and knuckle geometry on the manufactured parts; and repeat the evaluation for Design 2 so that the two designs can be compared on equal terms.

Acknowledgment

The authors thank [guide/organisation] for access to the progressive-die facility and the STAMPACK simulation environment.

REFERENCES

1. M. Ahmed, G. S. Sekhon, and D. Singh, "Finite element simulation of sheet metal forming processes," *Defence Sci. J.*, vol. 55, no. 4, pp. 389–401, Oct. 2005, doi: 10.14429/dsj.55.2002.
2. D. U. Furrer and S. L. Semiatin, Eds., *ASM Handbook, Vol. 22B: Metals Process Simulation*. Materials Park, OH, USA: ASM International, 2010.

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

3. A. Makinouchi, "Sheet metal forming simulation in industry," *J. Mater. Process. Technol.*, vol. 60, no. 1–4, pp. 19–26, 1996.
4. D. Banabic, A. Kami, D.-S. Comsa, and P. Eyckens, "Developments of the Marciniak–Kuczynski model for sheet metal formability: A review," *J. Mater. Process. Technol.*, vol. 287, Art. no. 116446, 2021.
5. L. Papeleux and J.-P. Ponthot, "Finite element simulation of springback in sheet metal forming," *J. Mater. Process. Technol.*, vol. 125–126, pp. 785–791, 2002.
6. Y. Yang and S. Hinduja, "Sequence planning of sheet metal parts manufactured using progressive dies," *Int. J. Adv. Manuf. Technol.*, 2022, doi: 10.1007/s00170-022-10389-8.
7. Quantech ATZ, "STAMPACK sheet metal forming simulation software." [Online]. Available: https://www.quantech.es