# Note on orthogonal chip forming (chip breaking)

# NOTE ON ORTHOGONAL CHIP FORMING

(Chip Breaking)

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## 1. Chip Former Geometry

The relevant geometric quantities of a chip former have been listed in fig. 1.
On the assumption, that the action of the chip former results in an uniform radius of bending of the chip it holds

$$r_m = (1-1_c) \cot \tfrac{1}{2}\beta - \tfrac{1}{2} t \qquad (1)$$

This curvature may arise either as a consequence of deformation of the shearplane or it is due to continuous plastic bending of the chip in the plane $O_1$ where the maximum value of the bending moment prevails {1}. It must be kept in mind that this latter case is not identical with the static plastic bending of a bar, where the radius of curvature would range between a minimum value in $O_1$ and infinite in A corresponding with the decreasing value of the bending moment. Due to the continuity of the chipping process the initial radius $r_m$ generated in $O_1$ is kept by the chip when neglecting the elastic spring back.
With an eye to mechanical strength the geometry of the chip former sometimes is chosen according to fig. 2 where formula 1 transforms into

$$r_m = (1-1_c-0.578)\ 1.73 - \tfrac{1}{2} t \qquad (2)$$

Chip breaking will take place when geometrical conditions allow the chip to hit either the workpiece or the tool, thus forcing a bending back of the chip to a larger radius of curvature accompanied by exceeding the yield strain of the chip's material.

## 2. Chip material

It can be assumed that in the case of cutting steel the material of the chip behaves in an ideal plastic way {2}.
The very high value of effective strain in cutting results in plastic saturation, which means that in the chip formed the strain hardening exponent is close to zero.
This implies {2.3} that the yield stress is strictly proportional to Vicker's hardness

$$H_v = 3{,}0\ \sigma_y \qquad (3)$$

Young's modulus of the chip material is temperature dependent. For the present purpose it is agreed on an average chip temperature of 600$^o$C, which gives {4}

$$E \simeq 15{,}75.10^4\ \text{N/mm}^2 \qquad (4)$$

This averaging of temperature and hence of Young's modulus in different cutting conditions of course introduces an apparent dependence of the yield strain on cutting conditions. In a more detailed analysis the chip temperature in each cutting condition must be measured and the corresponding value of Young's modulus used.
As it is clear that the cracked inside surface of the chip does not contribute to the mechanical strength of the chip the effective (solid) thickness $t_c$ is defined. This quantity has been measured seperately in every sample.

## 3. Experimental Procedure {5}

The chip formed with the initial radius $r_m$ springs back to a radius $R_o$.
Using for the case of simplicity an uniaxial stress model it holds

$$R_o = r_m \frac{\frac{2}{3} \frac{p^3}{t_e^2 - p^2} + t_e}{t_e - p}$$

where (5)

$$p = 2r_m \frac{\sigma_y}{E}$$

According to eqs.1 and 2 the initial radius can be determined from geometrical conditions, chip thickness and chip contact length. The latter has been measured from the wear pattern on the rake face of the tool.
Hardness measurements on the chip and using eqs. 3, 4, 5 allow for calculation of the radius $R_o$.
When the chip hits any obstacle and breaks it is locally bend to the radius $R_y$ corresponding to the value of the yield strain. Neglecting the elastic component and again using an uniaxial model it holds

$$\varepsilon_y = \tfrac{1}{2}\, t_e \left(\frac{1}{R_o} - \frac{1}{R_y}\right) \qquad (6)$$

In the samples collected from the lathe the broken chips are found with a radius R according to

$$\frac{\sigma_y}{E} = \tfrac{1}{2}\, t_e \left(\frac{1}{R} - \frac{1}{R_y}\right) \qquad (7)$$

Using the value of $\sigma_y$ known by the former step and measuring the value R thus gives the values of the yield radius and finally the yield strain of the chip.
In order to avoid BUE the cutting speed throughout the investigation is chosen 2.08 m/s with a P10 carbide tool. The depth of cut amounts 3.2 mm.
In the case of small values of feed a chip former as shown in fig. 1 has been used. To avoid confusion the chipformer distance in this case is represented by the symbol 1'.

The results of the measurements are collected in the tables I, II and III.

Table I / observations

| run nr. | chipformer 1' mm | distance 1 mm | feed mm/rev. | type of chip |
|---|---|---|---|---|
| 1 | 1.77 | (2.35) | 0.079 | broken |
| 2 | 1.86 | (2.44) | 0.100 | jammed |
| 3 | 1.86 | (2.44) | 0.125 | jammed |
| 4 | 1.99 | (2.57) | 0.158 | fragmented |
| 5 | 2.11 | (2.69) | 0.079 | curly |
| 6 | 2.12 | (2.70) | 0.100 | broken |
| 7 | 2.05 | (2.63) | 0.125 | broken |
| 8 | 2.34 | (2.92) | 0.158 | broken |
| 9 | 2.41 | (2.99) | 0.200 | fragmented |
| 10 | | 3.13 | 0.100 | curly |
| 11 | | 3.13 | 0.125 | curly + broken |
| 12 | | 3.23 | 0.158 | broken |
| 13 | | 3.33 | 0.200 | broken |
| 14 | | 3.18 | 0.250 | fragmented |
| 15 | | 3.48 | 0.125 | curly |
| 16 | | 3.42 | 0.158 | curly + broken |
| 17 | | 3.63 | 0.200 | broken |
| 18 | | 3.59 | 0.250 | broken |
| 19 | | 3.51 | 0.315 | fragmented |
| 20 | | 3.77 | 0.158 | curly |
| 21 | | 3.71 | 0.200 | broken |
| 22 | | 3.83 | 0.250 | broken |
| 23 | | 3.72 | 0.315 | fragmented |

Table II / measurements

| run.nr. | chip thickness mm | effective chip thickness mm | chip contact length mm | Vickers hardness $N/mm^2$ | final chip radius mm |
|---|---|---|---|---|---|
| 1 | 0.350 | 0.322 | 0.47 | 2570 | 5.2 |
| 4 | 0.514 | 0.485 | 0.59 | 2600 | - |
| 6 | 0.417 | 0.384 | 0.53 | 2650 | 6.3 |
| 7 | 0.466 | 0.431 | 0.56 | 2570 | 5.6 |
| 8 | 0.529 | 0.494 | 0.67 | 2590 | 5.6 |
| 9 | 0.592 | 0.555 | 0.68 | 2560 | 4.7 |
| 11 | 0.450 | 0.407 | 0.56 | 2500 | 6.9 |
| 12 | 0.510 | 0.447 | 0.66 | 2490 | 8.2 |
| 13 | 0.578 | 0.516 | 0.73 | 2430 | 6.3 |
| 16 | 0.501 | 0.444 | 0.68 | 2590 | 7.7 |
| 17 | 0.583 | 0.531 | 0.76 | 2590 | 6.7 |
| 18 | 0.662 | 0.604 | 0.81 | 2530 | 6.6 |
| 21 | 0.586 | 0.527 | 0.79 | 2470 | 7.7 |
| 22 | 0.676 | 0.612 | 0.87 | 2400 | 6.5 |

Table III / calculations

| run.nr. | $\sigma_y$ $N/mm^2$ | $r_m$ mm | $R_o$ mm | $R_y$ mm | $\varepsilon_y$ % |
|---|---|---|---|---|---|
| 1 | 860 | 2.09 | 2.24 | 6.3 | 4.6 |
| 6 | 880 | 2.56 | 2.77 | 7.7 | 4.4 |
| 7 | 860 | 2.36 | 2.52 | 6.6 | 5.3 |
| 8 | 860 | 2.64 | 2.86 | 6.4 | 4.8 |
| 9 | 850 | 2.71 | 2.86 | 5.2 | 4.4 |
| 11 | 830 | 3.24 | 3.53 | 8.4 | 3.3 |
| 12 | 830 | 3.22 | 3.48 | 10.3 | 4.3 |
| 13 | 810 | 3.24 | 3.45 | 7.2 | 3.9 |
| 16 | 860 | 3.52 | 3.85 | 9.5 | 3.4 |
| 17 | 860 | 3.69 | 4.01 | 7.8 | 3.2 |
| 18 | 840 | 3.51 | 3.74 | 7.5 | 4.0 |
| 21 | 820 | 3.79 | 4.11 | 9.1 | 3.5 |
| 22 | 800 | 3.81 | 4.06 | 7.3 | 3.3 |

As shown in graph fig. 3 the yield strain proves to be practically independent on the feed but shows a tendency to increase at smaller values of the chip former distance. As remarked earlier this effect is probably due to differences in chip temperature.

## 4. Optimal conditions

The observations listed in table I do not refer to optimal conditions in the region between forming of continuous chips and broken chips. As the lathe available is not equiped with continuous feed control in the present experiments the chip former distance is changed at constant feed rate up to the transition point where both types of chips are cut. The broken chips have been sampled in order to determine their values R, t and $t_e$.
An example is shown in table IV.

Table IV

feed 0,158 $^{mm}/rev.$

optimal conditions 1 = 3.56 mm

| R mm | t mm | $t - t_e$ mm |
|---|---|---|
| 8.5 | 0.49 | 0.055 |
| 11.25 | 0.50 | 0.068 |
| 10.0 | 0.50 | 0.070 |
| 10.75 | 0.49 | 0.052 |
| 10.25 | 0.49 | 0.060 |
| 10.1 | 0.50 | 0.061 |

The yield stress is averaged from table III at $\sigma_y$ = 840 N/mm$^2$
Applying eq. 7 renders

$$R_{opt} = 13.4 \text{ mm}$$

Averaging the value of the yield strain in the region investigated at $\varepsilon_y$ = 3.5% formula 6 gives $R_o$ = 4.31 mm.

From eq. 5 it follows $r_m = 3.90$ mm and hence formula 2 renders $l = 3.68$ mm.
The results obtained this way have been listed in Table V.

Table V
optimal chip former distance

| feed mm/rev. | chip former distance mm |
|---|---|
| 0.079 | 2.55 |
| 0.1 | 2.97 |
| 0.125 | 3.32 |
| 0.158 | 3.68 |
| 0.2 | 4.08 |

The graph fig. 4 presents this curve of critical or optimal conditions compared with experimental observation.

## 5. Conclusion

This note elucidates the principal possibility of determining on the basis of a simple mechanical model the relation between feedrate and chip former distance in order to obtain long broken chips in cutting particularly in the important region of low feed rates. Decreasing of the chip former distance promotes the creation of short-broken and fragmented chips and on the contrary increasing of the optimal distance causes forming of curly continuous chips.
To enable the necessary calculations several fundamental quantities must be known like hardness and yield strain of the chip material, chip contact length and effective chip thickness.
It is obvious that some of these depend on cutting conditions and toolgeometry which greatly complicates the problem.

## References


{1} Pekelharing, A.J. CIRP Pittsburgh 1963

{2} Nakayama, K. Int. Res. Prod. Eng. 1963

{3} Tabor, D. The Hardness of Metals, Londen 1951

{4} Roberts, M.H.
Nortcliffe, J. Journ. Iron Steel Inst., nov. 1947

{5} Hogenboom, J.M. graduate work 1967, Eindhoven


## Symbols

| | | |
|---|---|---|
| $l$, $l'$ | chip former distance | mm |
| $l_c$ | chip contact length | mm |
| $\beta$ | chip former angle | rad |
| $t$ | chip thickness | mm |
| $t_e$ | effective chip thickness | mm |
| $r_m$ | initial chip radius | mm |
| $R_o$ | chip radius after spring back | mm |
| $R_y$ | yield radius | mm |
| $R$ | final chip radius | mm |
| $\varepsilon_y$ | yield strain | - |
| $\sigma_y$ | yield stress | $N/mm^2$ |
| $H_v$ | vickers hardness | $N/mm^2$ |
| $E$ | Young's modulus | $N/mm^2$ |

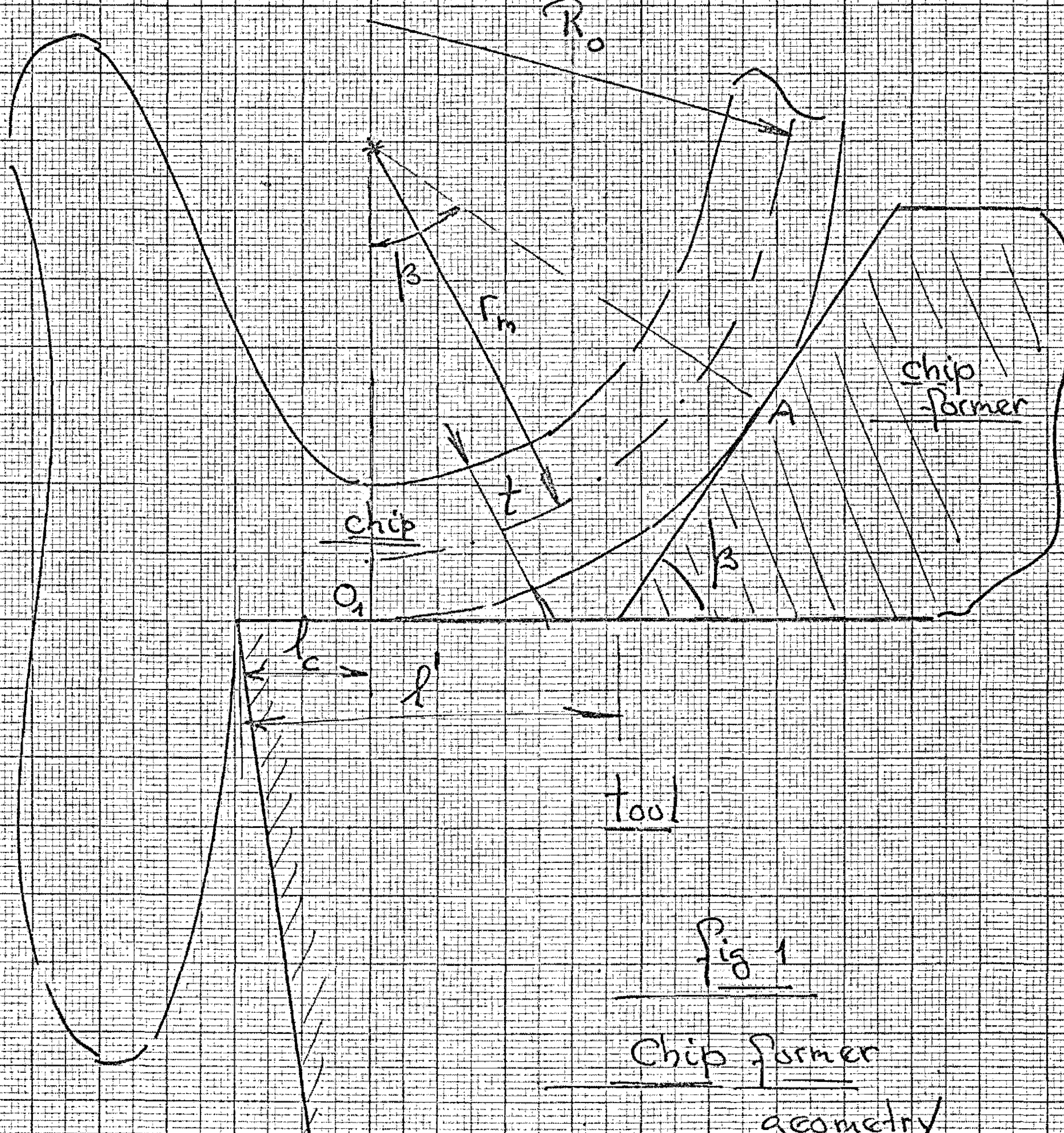



fig 1

Chip former geometry type I

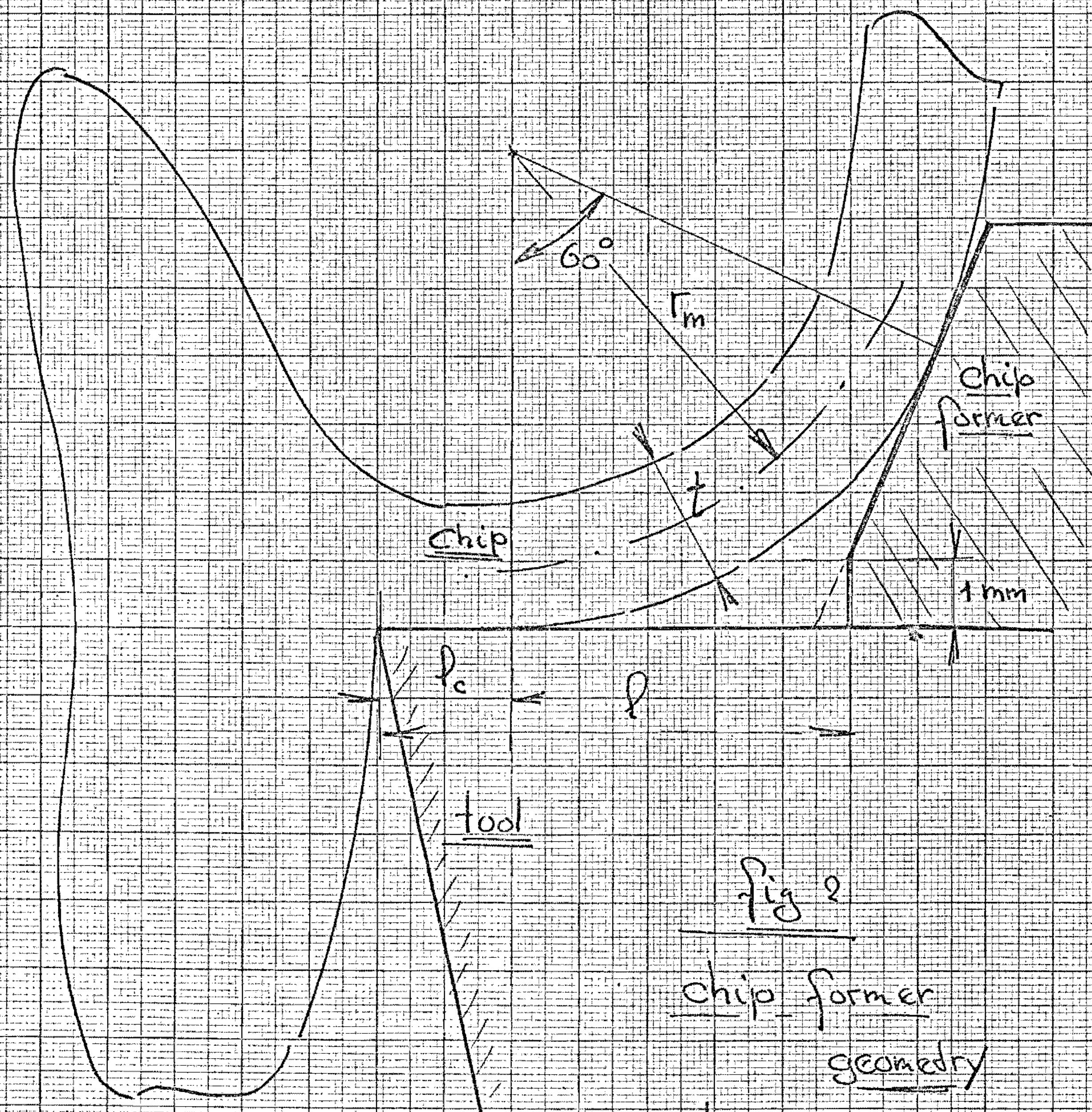
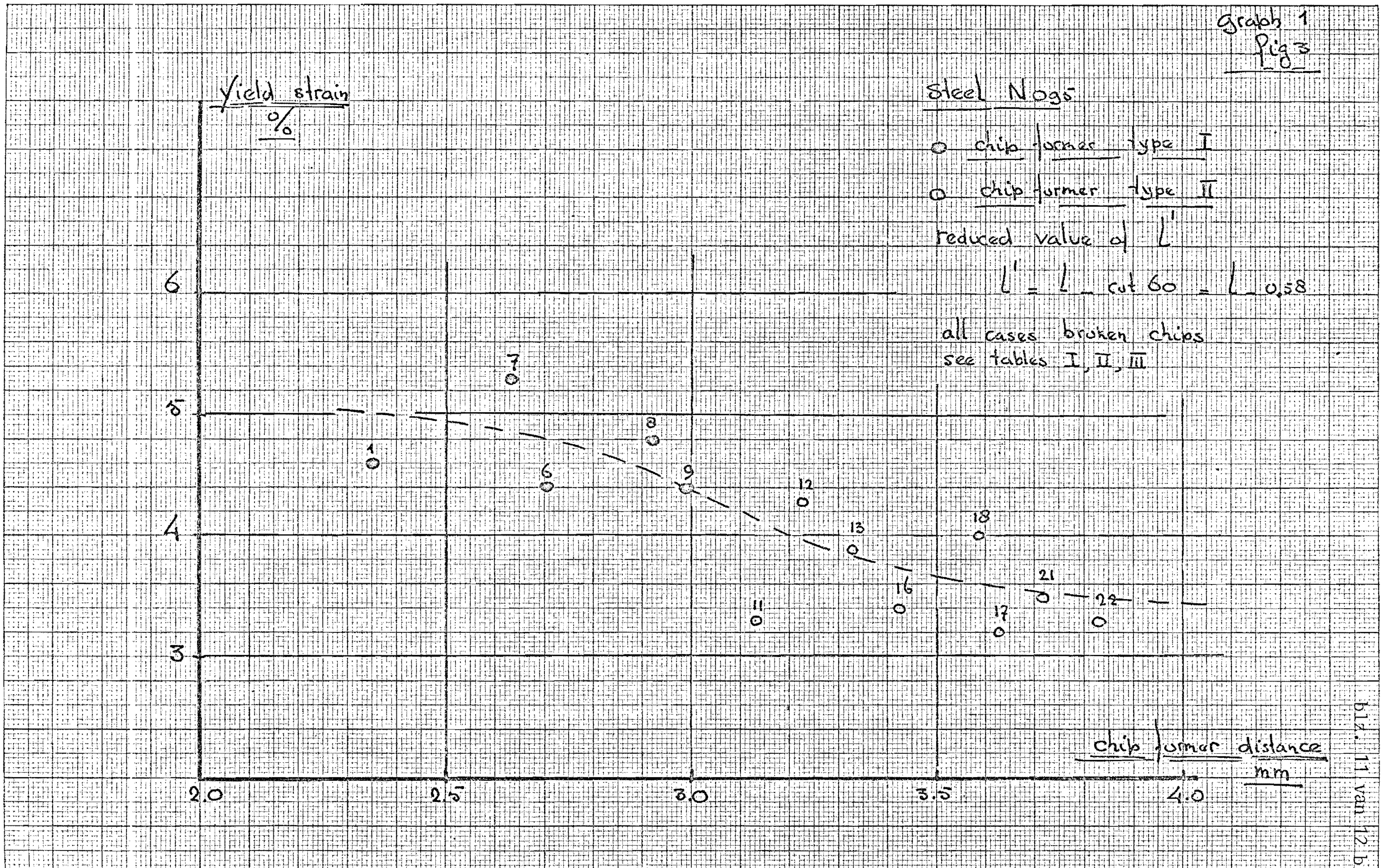
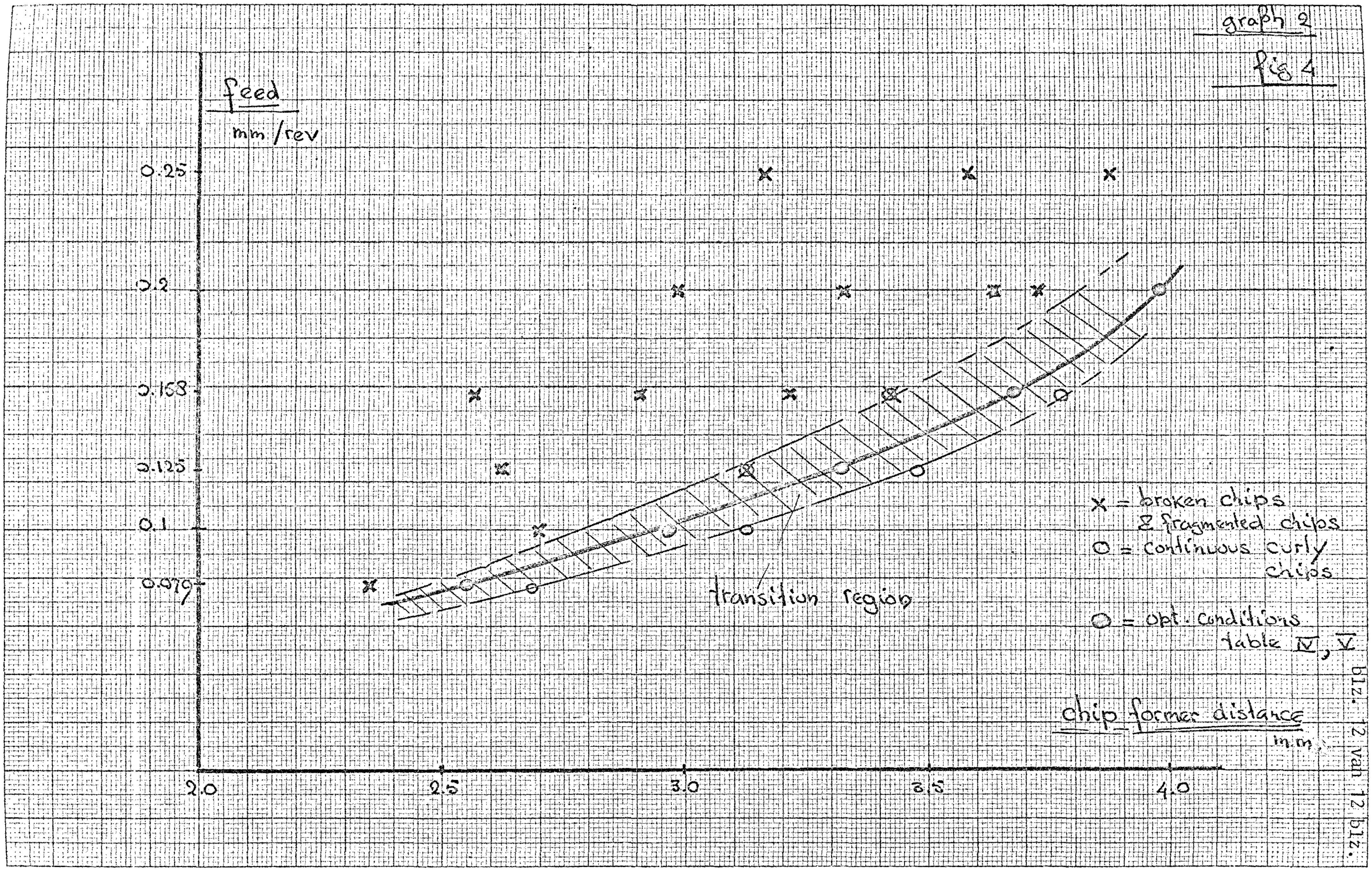



fig 2

Chip former geometry type II


Graph 1
Fig 3
Yield strain %
Steel No 95
chip former type I
chip former type II
reduced value of L'
L' = L . cot 60 = L . 0,58
all cases broken chips
see tables I, II, III
chip former distance mm
2.0
2.5
3.0
3.5
4.0
3
4
5
6
1
6
7
8
9
11
12
13
16
17
18
21
22



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