The Formability of Perforated Metals, Part II: Stainless Steel and Aluminum

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THE OSU FORMABILITY TEST

Forming processes are among the most frequently used in the fabrication of perforated metals. Formability is the term used to evaluate the capacity of a material to withstand the stretch/draw stresses of forming before splitting occurs. We have had a long-standing interest in testing formability because the standard mechanical tests to evaluating strength in materials, such as the tensile tests, had not correlated well with what actually occurs in forming operations.

Standard formability tests, such as the Limiting Dome Height test (LDH) showed good correlation to press performance, but required high capital investment (upward of $200,000) and lacked the ability to provide consistent from one location or machine to another.

Ohio State University and Interlaken Technology Corporation, with sponsorship by the Edison Materials Technology Center (EMTEC) designed a reproducible, accurate formability test and an inexpensive formability testing machine. Following a study conducted by General Motors Corp. that found that 80% of splitting failures occur near the plane strain condition, the OSU Formability Test reliably reproduces this strain state.

After several years work, the team succeeded in designing and refining both the machine and tooling for measuring formability to yield testing results that had one tenth the variation found in the old LDH tests, with time to peform reduced by a factor of 5 to 10, and a machine capital cost of approximately $50,000. The formability test machine has now been commercialized and more than 10 of them are in use in industry during the first years of availability. These improvements make formability testing a practical reality for all sizes of forming companies.

Goals

Measure the formability of perforated sheets of stainless steel and aluminum and to develop the following relationships:

1. Effect of % open area on formability.
2. Effect of thickness and hole size on formability.
3. Differences in the formability of materials- aluminum alloys 3003, 5052 and 6061 and the stainless steel types 304L, 316L and 409.

Procedure

Each sample was cleaned with acetone followed by methanol and drying. The sample was lubricated with oil in the region of punch contact. The sample was placed in the OSU formability tooling and clamped. The punch was then advanced at a rate of 1 mm/sec until failure occurred.

For each test the measure of formability was the punch height at which the material sustained a maximum load was obtained from the recorded load versus displacement data. Three tests were performed on each of the 90 test conditions requested and the punch heights recorded for each were averaged.

Test Results

Table 1 summarizes the materials and perforation spacing tested. For each hole diameter, different hole spacing giving rise to different percent open areas which have been summarized.

Table 2 summarizes formability measurements for the 90 tests performed. The results are grouped by the pattern and size of holes, then ordered by material and gauge. The mode of failure (either single failure,.S, or multiple failure, M) and the places where failure was observed (near die, D, near punch, P, or center, C). A blank in

these columns means that the failure was not uniquely located. The effect of each of the variables on how they affect formability has been considered and explained with the help of plots and charts in the following sections.

Effect of percent open area

The % open area was plotted against the punch height at maximum load. Charts 1-6 show this variation for each of the materials. Each plot contains a series of curves for various hole sizes and thickness, as noted in the legend of the plot. The hole size is given in mm and the thickness is given as the gauge number.

The results show that there is a drop in formability as the % open area increases. However for aluminum 3003, the trends were not very clear. The reason for this could be that the punch height at which these were failing was too small and the specimen failed in a very short time. Hence the scatter in the values is expected to be high and the test may not be sufficiently accurate to deduce a trend.

Chart 1: Effect of Open Area on Formability
3003 Aluminum

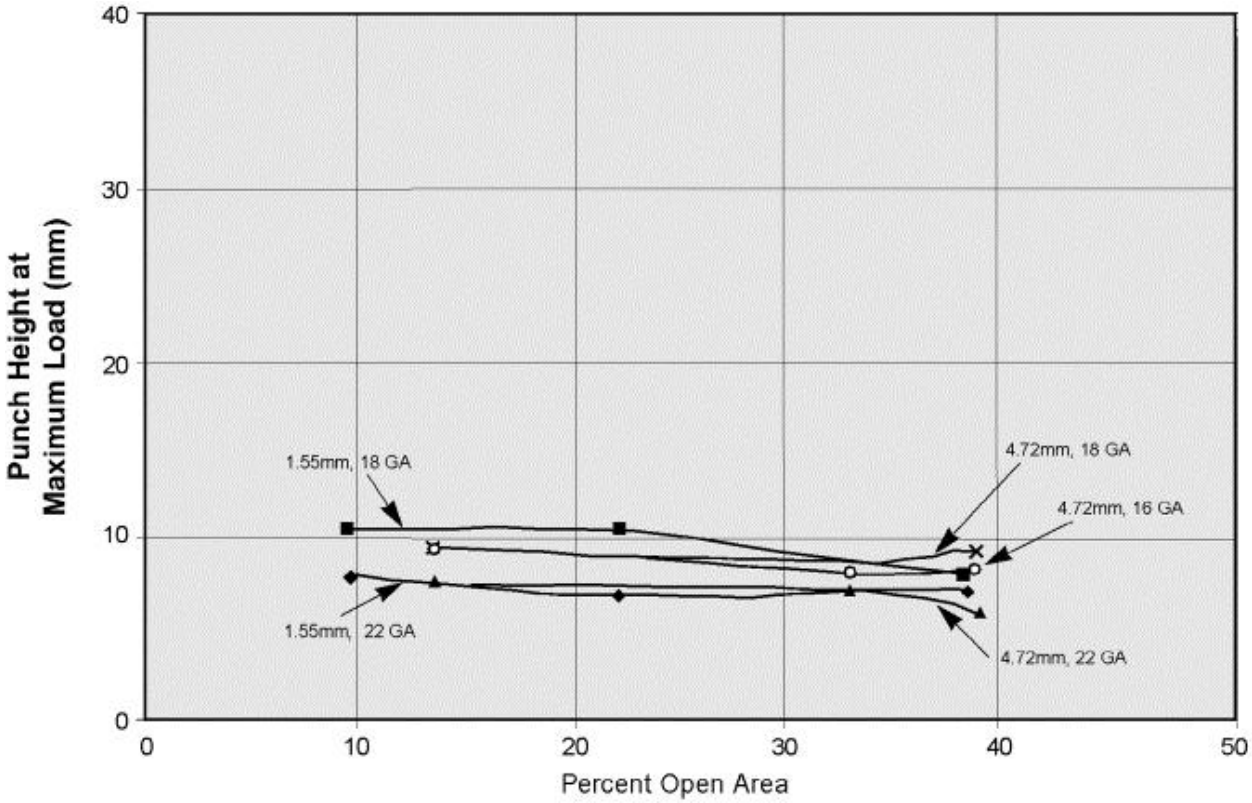


Chart 2: Effect of Open Area on Formability
5052 Aluminum

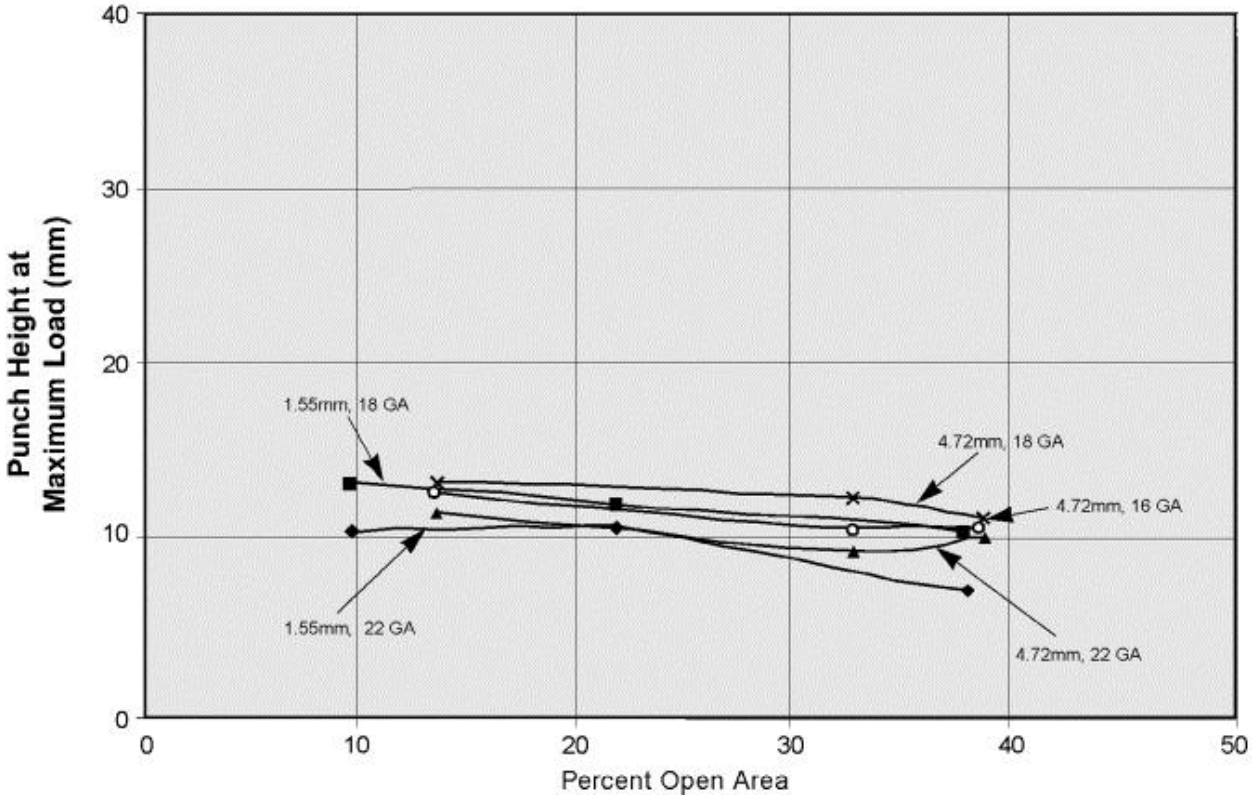


Chart 3: Effect of Open Area on Formability
6061 Aluminum

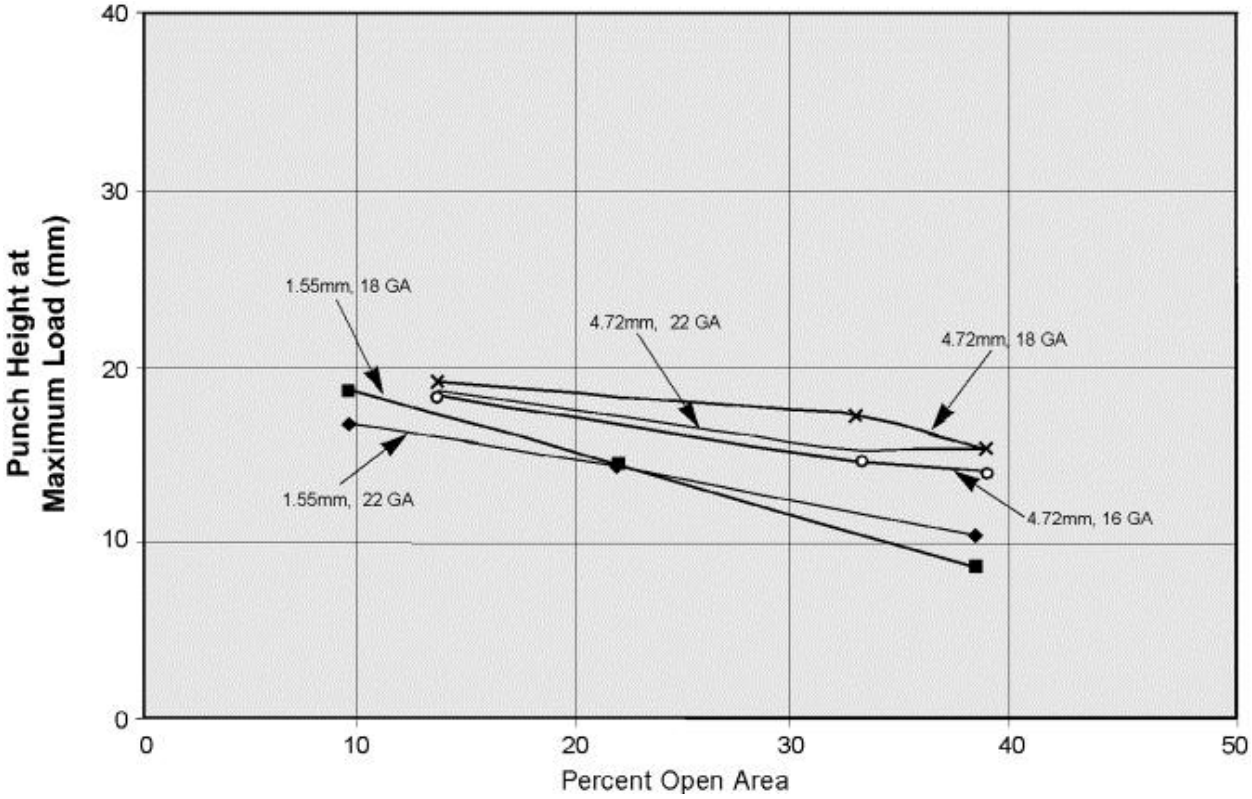


Chart 4: Effect of Open Area on Formability
304 L Stainless Steel

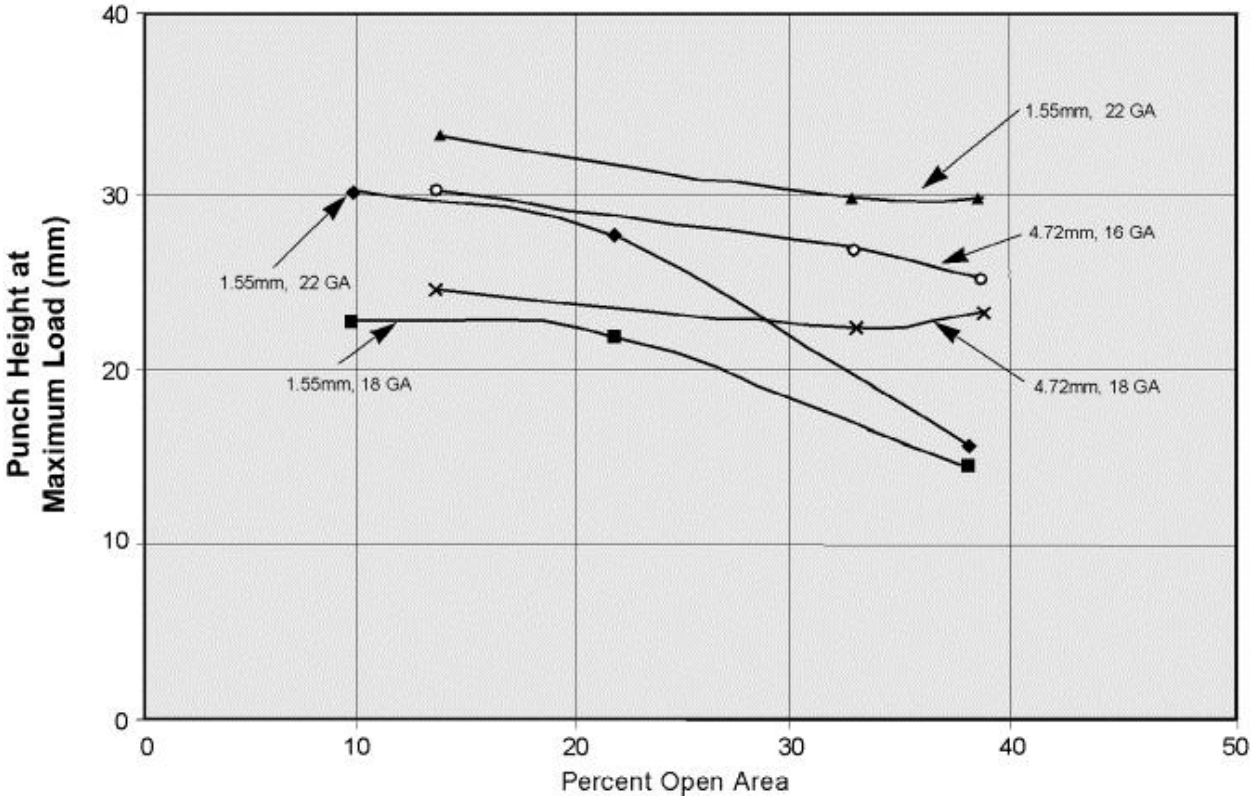


Chart 5: Effect of Open Area on Formability
316 L Stainless Steel

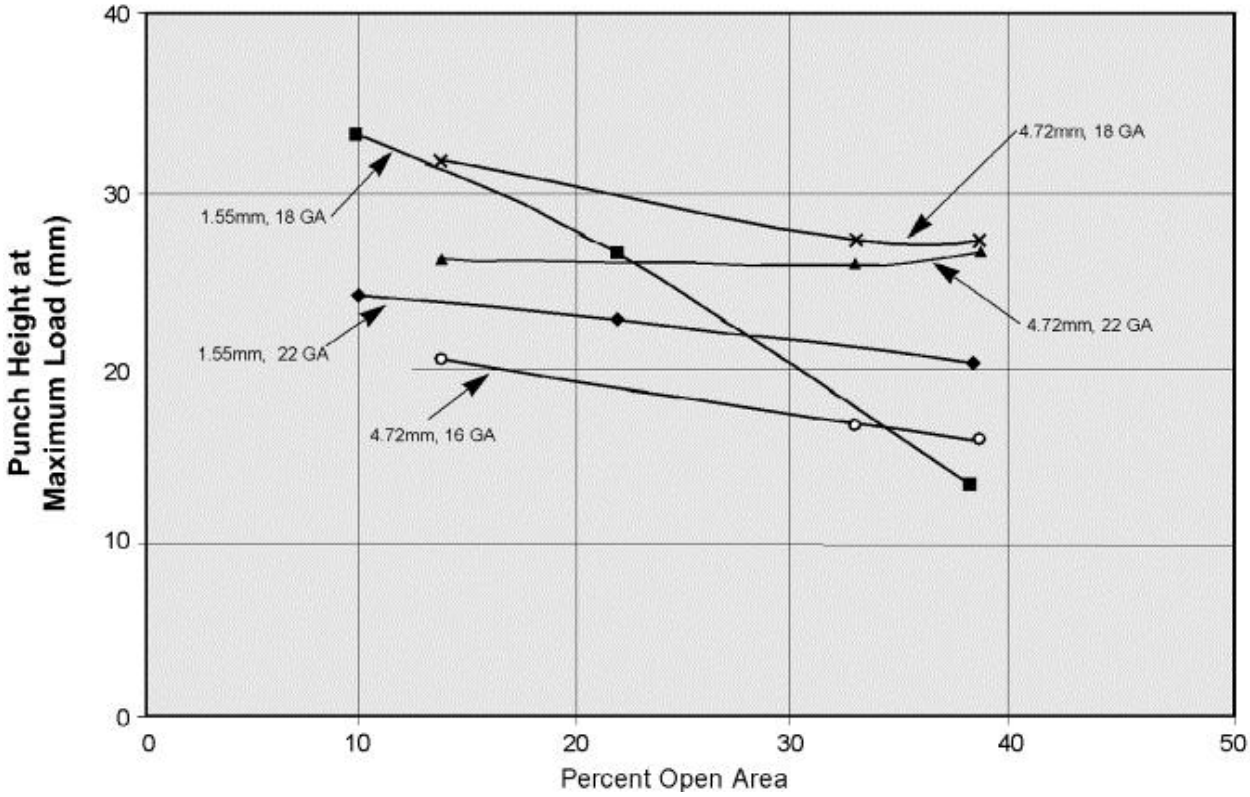
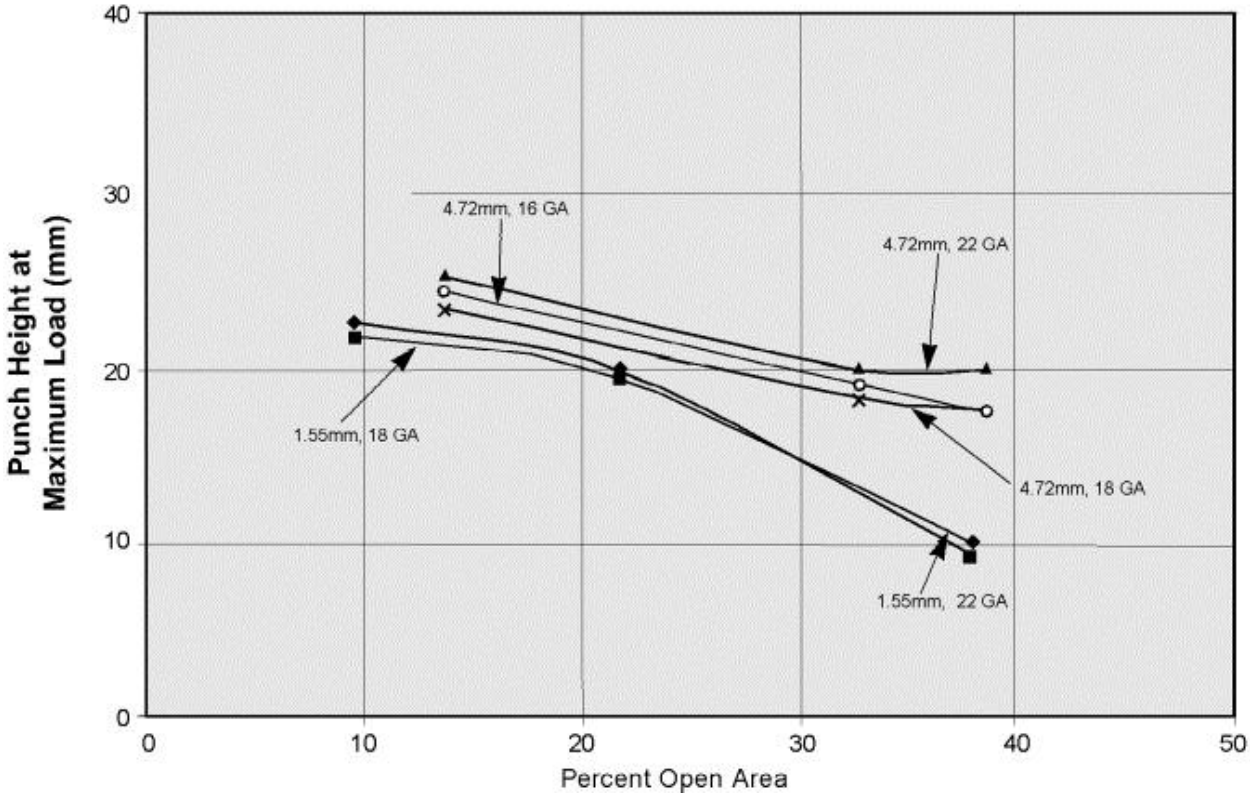


Chart 6: Effect of Open Area on Formability
409 Stainless Steel



Effect of thickness and hole size

The plot average of punch heights (averaged over all choices of % open area) versus thickness are shown in Charts 7-12. Each of these has graphs for the 2 choices of hole size: 4.71 mm and 1.55 mm.

These charts do not show any consistent trend of formability with thickness. However it can be seen that the formability of the sheets with 1.55 mm holes is consistently less than that of the specimens with 4.72 mm holes.

Chart 7: Effect of Thickness and Hole Size on Formability
3003 Aluminum

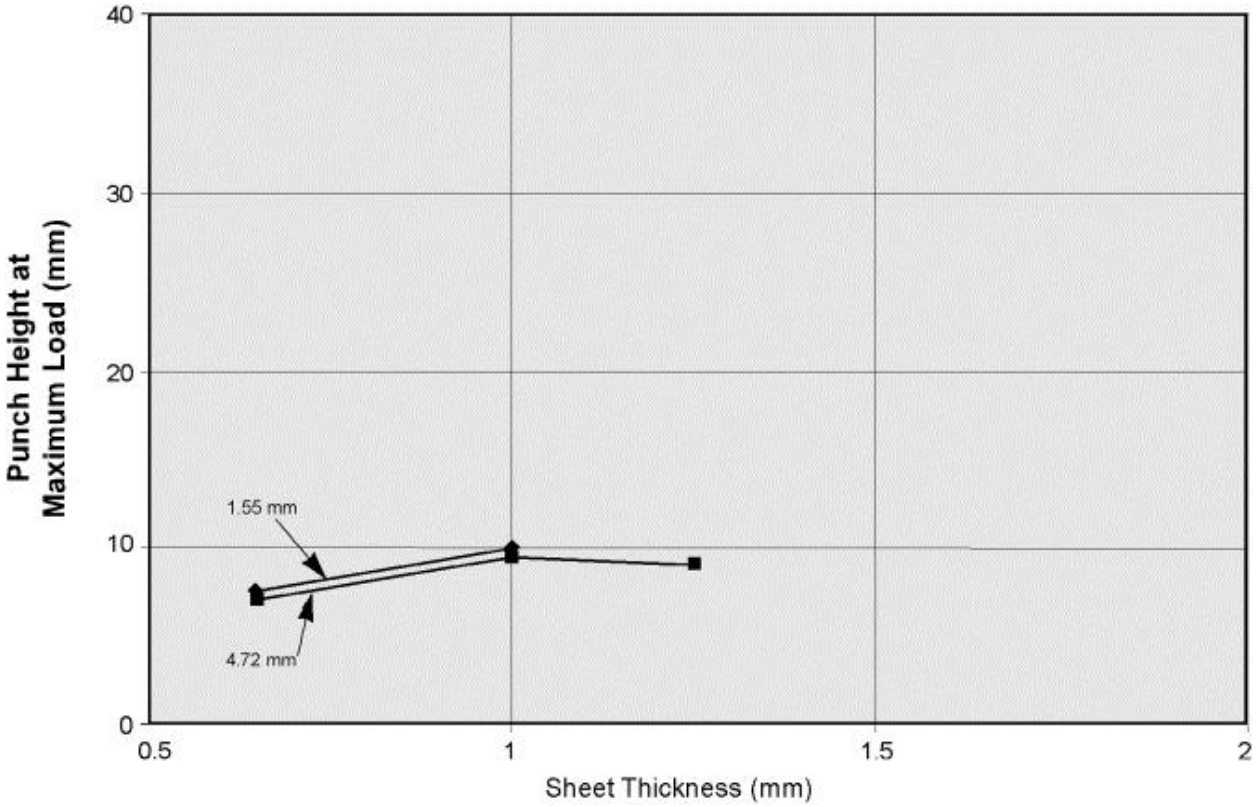


Chart 8: Effect of Thickness and Hole Size on Formability
5052 Aluminum

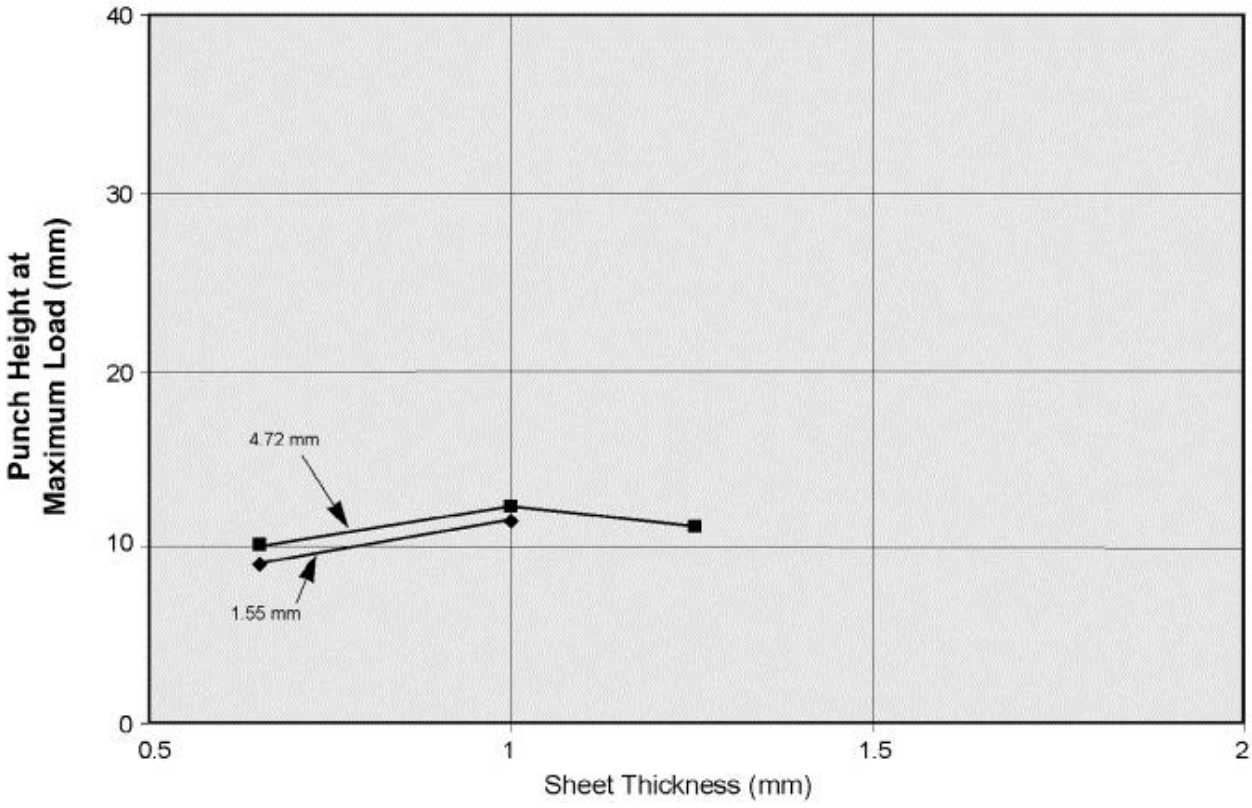


Chart 9: Effect of Thickness and Hole Size on Formability
6061 Aluminum

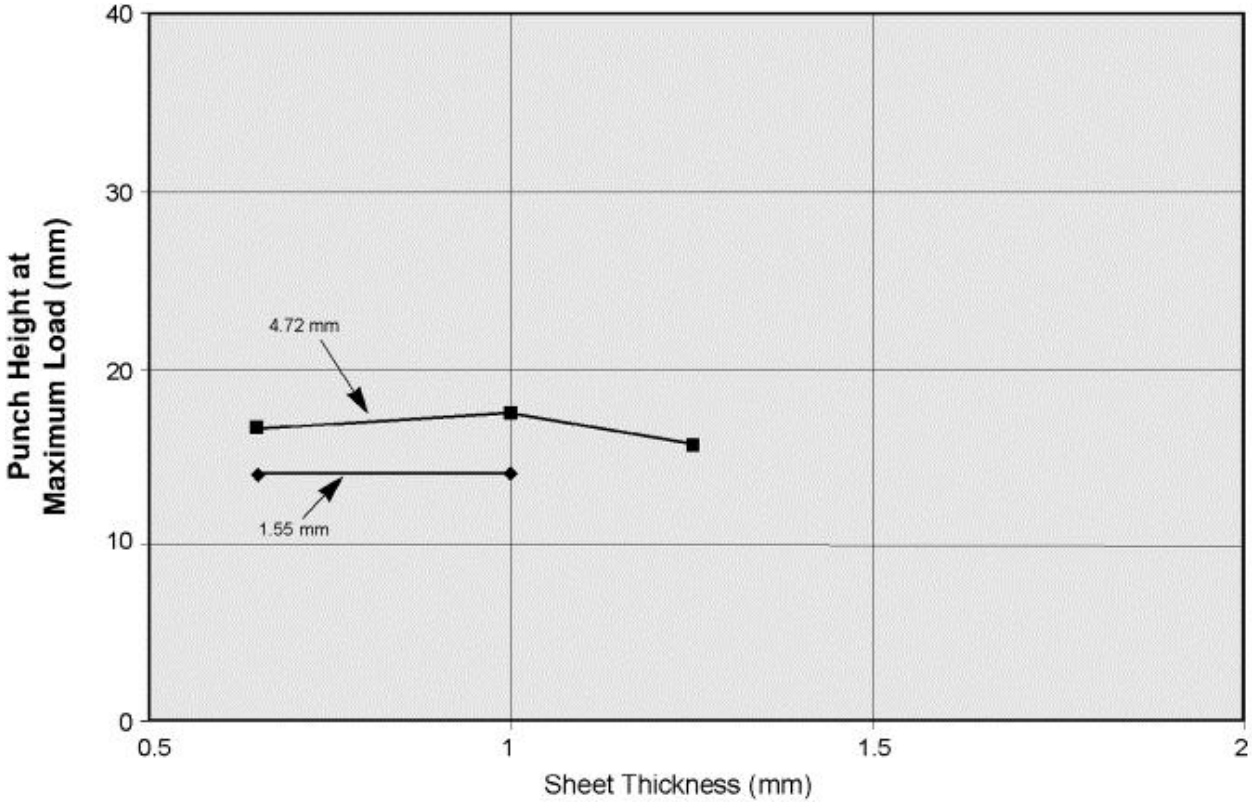


Chart 10: Effect of Thickness and Hole Size on Formability
304 L Stainless Steel

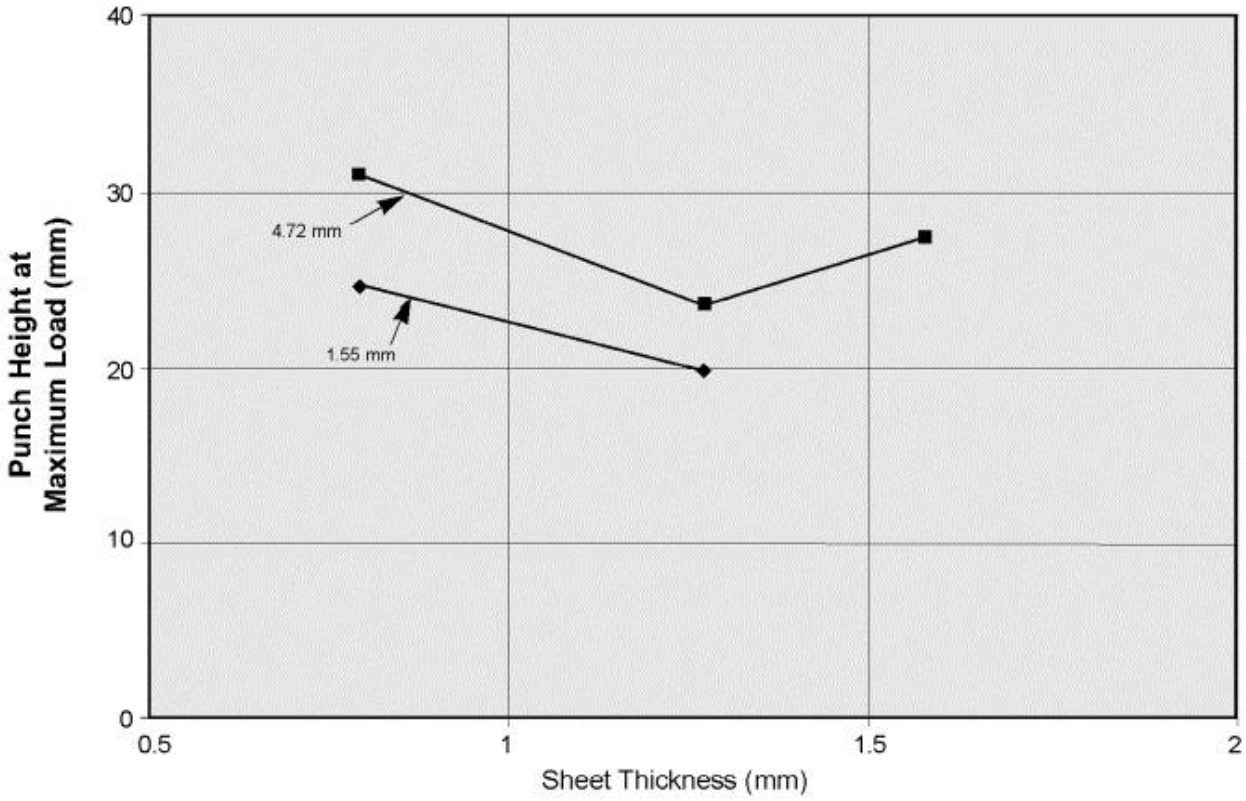


Chart 11: Effect of Thickness and Hole Size on Formability
316 L Stainless Steel

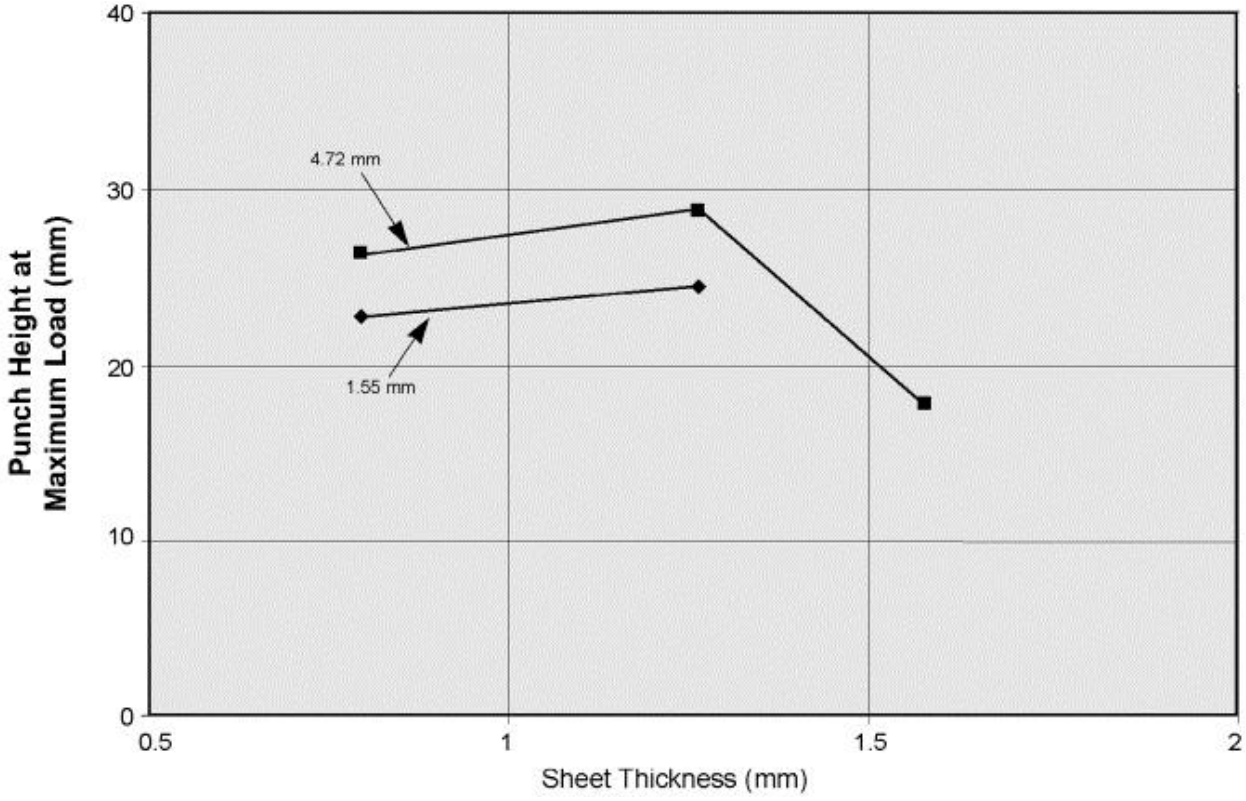
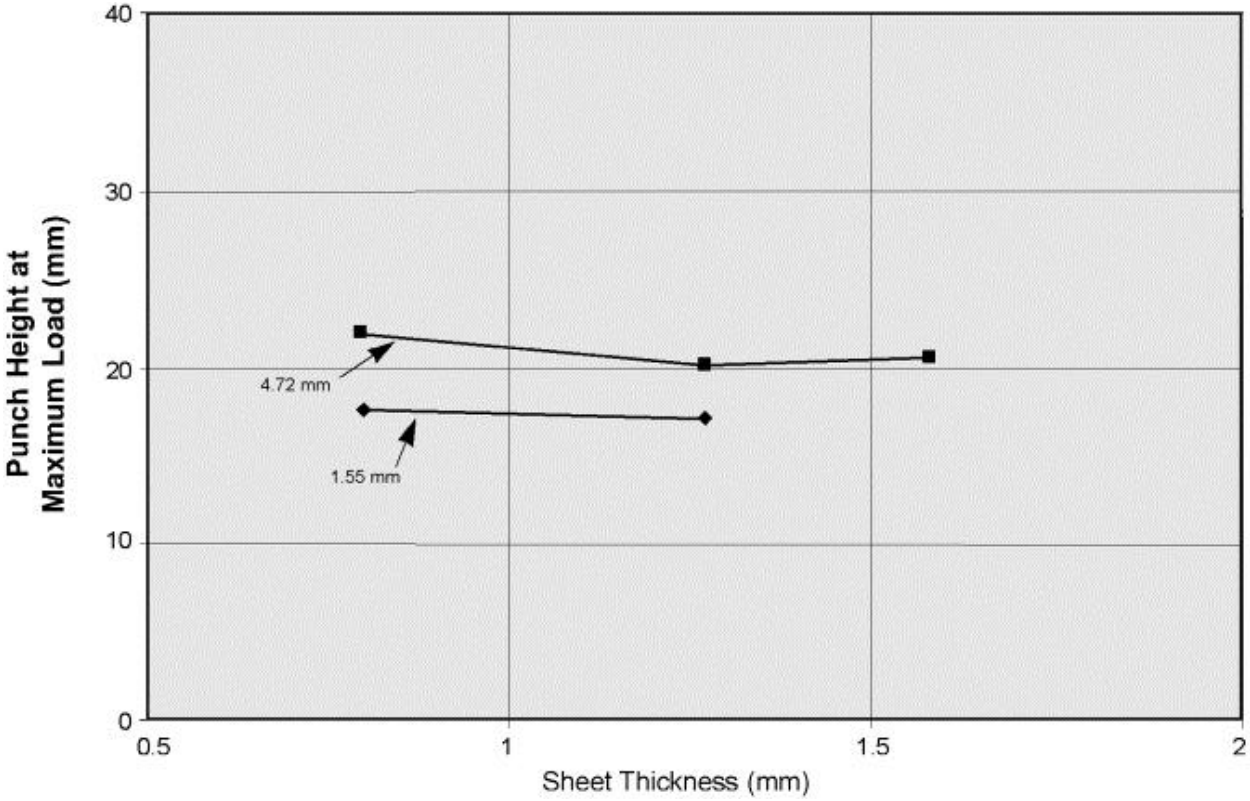


Chart 12: Effect of Thickness and Hole Size on Formability
409 Stainless Steel



Material Comparison

The 6 materials were compared by taking the average formability of all the tests with that material. This average punch height has been compared by means of chart 13.

It clearly shows that the perforated aluminum sheets have a lower formability than steel sheets. Aluminum 3003 has the least formability whereas Stainless Steel 304L has the highest formability.

Chart 13: Relative Formability of Materials Tested

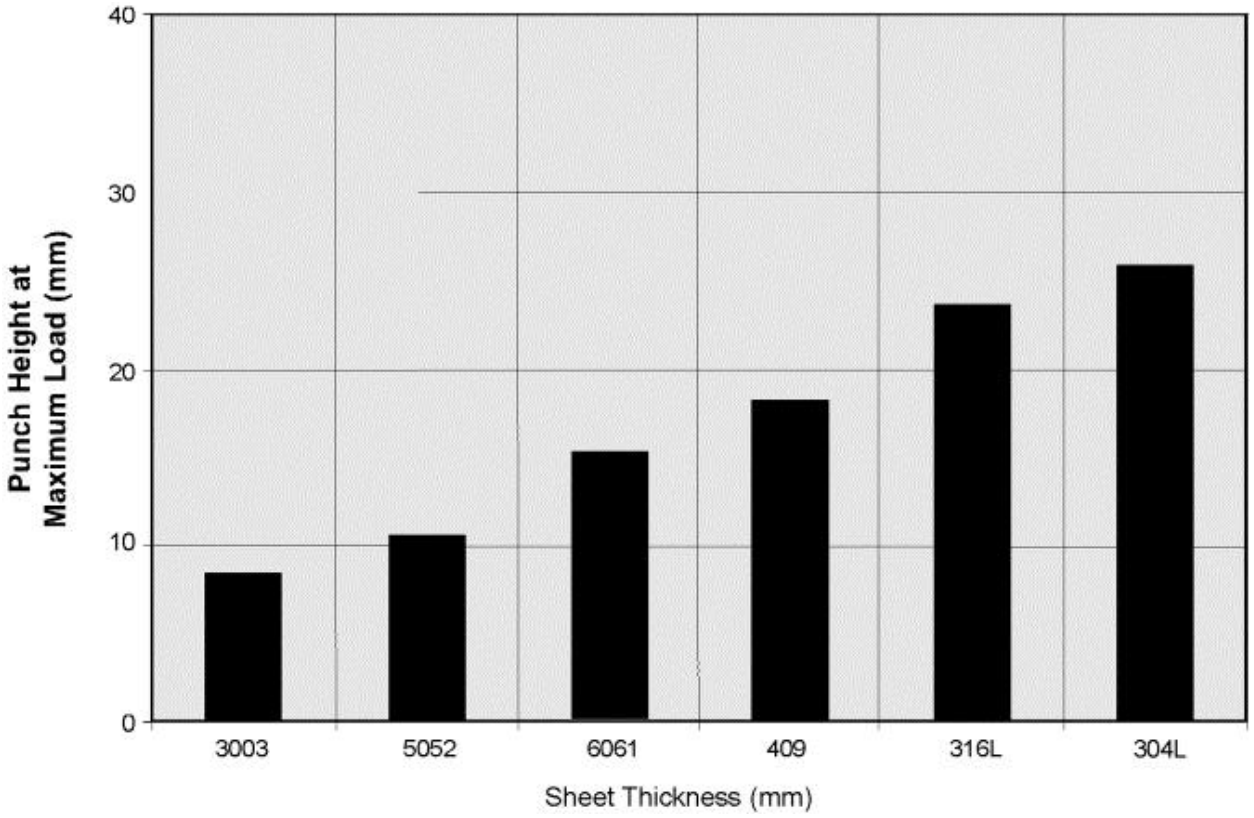


Table 1: Summary of Materials and Perforation Patterns Tested

Material	Thickness (ga)	Measured Thickness (mm)	Hole Dia. (mm)
AL 3003	22	0.65	1.55, 4.72
	18	1.00	1.55, 4.72
	16	1.25	4.72
AL 5052	22	0,65	1.55, 4.72
	18	1.00	1.55, 4.72
	16	1.25	4.72
AL 6061	22	0.65	1.55, 4.72
	18	1.00	1.55, 4.72
	16	1.25	4.72
STN 304L	22	0.79	1.55, 4.72
	18	1.27	1.55, 4.72
	16	1.59	4.72
STN 316L	22	0.79	1.55, 4.72
	18	1.27	1.55, 4.72
	16	1.59	4.72
STN 409	22	0.79	1.55, 4.72
	18	1.27	1.55, 4.72
	16	1.59	4.72

Table of Formability Test Results

No.	Pattern	Material	GA	Hole Dia (mm)	No. of Holes	Hole Area (sq. mm)	Open Area %	Av. Ht. (mm)	Failure Site	Mode of Failure
1	1/16 x 1/8	ALUM 3003	22	1.55	2632	4967	21.79	6.9	C,D	S
2	1/16 x 1/8	ALUM 3003	18	1.55	2632	4967	21.79	10.6	C,P	S
3	1/16 x 1/8	ALUM 5052	22	1.55	2632	4967	21.79	10.6	C,D	S
4	1/16 x 1/8	ALUM 5052	18	1.55	2632	4967	21.79	11.9	C	S
5	1/16 x 1/8	ALUM 6061	22	1.55	2632	4967	21.79	14.5	C	S
6	1/16 x 1/8	ALUM 6061	18	1.55	2632	4967	21.79	14.5	C	M
7	1/16 x 1/8	STN 409	22	1.55	2632	4967	21.79	19.8	C	S,M
8	1/16 x 1/8	STN 409	18	1.55	2632	4967	21.79	19.3	C	S,M
9	1/16 x 1/8	STN 304 L	22	1.55	2632	4967	21.79	27.7	C	S
10	1/16 x 1/8	STN 304 L	18	1.55	2632	4967	21.79	22.3	C	S
11	1/16 x 1/8	STN 316 L	22	1.55	2632	4967	21.79	22.9	C	S,M
12	1/16 x 1/8	STN 316 L	18	1.55	2632	4967	21.79	26.6	C	S
13	1/16 x 3/16	ALUM 3003	22	1.55	1173	2214	9.71	8.1	P,D	S
14	1/16 x 3/16	ALUM 3003	18	1.55	1173	2214	9.71	10.6	D	S
15	1/16 x 3/16	ALUM 5052	22	1.55	1173	2214	9.71	10.3	-	-
16	1/16 x 3/16	ALUM 5052	18	1.55	1173	2214	9.71	13.1	-	M
17	1/16 x 3/16	ALUM 6061	22	1.55	1173	2214	9.71	16.8	-	M
18	1/16 x 3/16	ALUM 6061	18	1.55	1173	2214	9.71	18.7	C,P	M
19	1/16 x 3/16	STN 409	22	1.55	1173	2214	9.71	22.4	C	S
20	1/16 x 3/16	STN 409	18	1.55	1173	2214	9.71	21.7	C	M
21	1/16 x 3/16	STN 304 L	22	1.55	1173	2214	9.71	30.2	C	S,M
22	1/16 x 3/16	STN 304 L	18	1.55	1173	2214	9.71	23.1	C	S,M
23	1/16 x 3/16	STN 316 L	18	1.55	1173	2214	9.71	33.1	C	S,M
24	1/16 x 3/16	STN 316 L	22	1.55	1173	2214	9.71	24.3	C	S,M
25	1/16 x 3/32	ALUM 3003	22	1.55	4600	8681	38.07	7.4	C	S
26	1/16 x 3/32	ALUM 5052	22	1.55	4600	8681	38.07	6.8	D	S,M
27	1/16 x 3/32	ALUM 5052	18	1.55	4600	8681	38.07	10.4	-	S
28	1/16 x 3/32	ALUM 6061	22	1.55	4600	8681	38.07	10.6	P	S
29	1/16 x 3/32	ALUM 6061	18	1.55	4600	8681	38.07	8.8	-	-
30	1/16 x 3/32	STN 409	22	1.55	4600	8681	38.07	9.5	P	S,M
31	1/16 x 3/32	STN 304 L	22	1.55	4600	8681	38.07	16.1	C	S
32	1/16 x 3/32	STN 304 L	18	1.55	4600	8681	38.07	14.9	C	S
33	1/16 x 3/32	STN 316 L	22	1.55	4600	8681	38.07	20.4	C,P	S
34	1/16 x 3/32	STN 316 L	18	1.55	4600	8681	38.07	13.7	-	S
35	1/16 x 3/32	ALUM 3003	18	1.55	4600	8681	38.07	8.1	C,P	S
36	1/16 x 3/32	STN 409	18	1.55	4600	8681	38.07	10.0	C	S

Table of Formability Test Results, continued

No.	Pattern	Material	GA	Hole Dia (mm)	No. of Holes	Hole Area (sq. mm)	Open Area %	Av. Ht. (mm)	Failure Site	Mode of Failure
37	3/16 x 1/2	ALUM 5052	22	4.72	175	3062	13.43	11.4	C	M
38	3/16 x 1/2	ALUM 3003	22	4.72	175	3062	13.43	7.6	C	M
39	3/16 x 1/2	ALUM 3003	18	4.72	175	3062	13.43	9.7	D	S
40	3/16 x 1/2	ALUM 3003	16	4.72	175	3062	13.43	9.8	D	S
41	3/16 x 1/2	ALUM 5052	18	4.72	175	3062	13.43	13.2	P	S,M
42	3/16 x 1/2	ALUM 5052	18	4.72	175	3062	13.43	12.7	C	S
43	3/16 x 1/2	ALUM 6061	22	4.72	175	3062	13.43	18.9	C,D	S,M
44	3/16 x 1/2	ALUM 6061	18	4.72	175	3062	13.43	19.3	C	S,M
45	3/16 x 1/2	ALUM 6061	16	4.72	175	3062	13.43	18.4	C	S,M
46	3/16 x 1/2	STN 409	22	4.72	175	3062	13.43	25.2	C	S
47	3/16 x 1/2	STN 409	18	4.72	175	3062	13.43	23.4	C	S
48	3/16 x 1/2	STN 409	16	4.72	175	3062	13.43	24.3	C	S
49	3/16 x 1/2	STN 304 L	22	4.72	175	3062	13.43	33.2	C	S
50	3/16 x 1/2	STN 304 L	18	4.72	175	3062	13.43	24.8	C	S,M
51	3/16 x 1/2	STN 304 L	16	4.72	175	3062	13.43	30.3	C	S,M
52	3/16 x 1/2	STN 316 L	22	4.72	175	3062	13.43	26.3	C	S,M
53	3/16 x 1/2	STN 316 L	18	4.72	175	3062	13.43	31.7	C	S
54	3/16 x 1/2	STN 316 L	16	4.72	175	3062	13.43	20.7	C	M
55	3/16 x 5/16	ALUM 3003	22	4.72	426	7455	32.70	7.4	D	S
56	3/16 x 5/16	ALUM 3003	18	4.72	426	7455	32.70	8.8	P	S
57	3/16 x 5/16	ALUM 3003	16	4.72	426	7455	32.70	8.3	D	S
58	3/16 x 5/16	ALUM 5052	22	4.72	426	7455	32.70	9.2	-	-
59	3/16 x 5/16	ALUM 5052	18	4.72	426	7455	32.70	12.3	P,D	S
60	3/16 x 5/16	ALUM 5052	18	4.72	426	7455	32.70	10.6	P,D	S
61	3/16 x 5/16	ALUM 6061	22	4.72	426	7455	32.70	15.3	C	M
62	3/16 x 5/16	ALUM 6061	18	4.72	426	7455	32.70	17.5	C	M
63	3/16 x 5/16	ALUM 6061	16	4.72	426	7455	32.70	14.7	C	S
64	3/16 x 5/16	STN 409	22	4.72	426	7455	32.70	19.9	C	M
65	3/16 x 5/16	STN 409	18	4.72	426	7455	32.70	18.4	C	S
66	3/16 x 5/16	STN 409	16	4.72	426	7455	32.70	19.0	P	S
67	3/16 x 5/16	STN 304 L	22	4.72	426	7455	32.70	29.9	C	S
68	3/16 x 5/16	STN 304 L	18	4.72	426	7455	32.70	22.7	C	S
69	3/16 x 5/16	STN 304 L	16	4.72	426	7455	32.70	27.1	C	S
70	3/16 x 5/16	STN 316 L	22	4.72	426	7455	32.70	25.9	C	S
71	3/16 x 5/16	STN 316 L	18	4.72	426	7455	32.70	27.3	C	S
72	3/16 x 5/16	STN 316 L	16	4.72	426	7455	32.70	17.1	C	S

Table of Formability Test Results, continued

No.	Pattern	Material	GA	Hole Dia (mm)	No. of Holes	Hole Area (sq. mm)	Open Area %	Av. Ht. (mm)	Failure Site	Mode of Failure
73	3/16 x 9/32	ALUM 3003	22	4.72	503	8802	38.61	6.2	C	M
74	3/16 x 9/32	ALUM 3003	18	4.72	503	8802	38.61	9.7	P,D	S
75	3/16 x 9/32	ALUM 3003	16	4.72	503	503	8802	38.61	8.4	D,S
76	3/16 x 9/32	ALUM 5052	22	4.72	503	8802	38.61	10.1	C,D	S
77	3/16 x 9/32	ALUM 5052	18	4.72	503	8802	38.61	11.3	C	S
78	3/16 x 9/32	ALUM 5052	16	4.72	503	8802	38.61	10.7	P	S
79	3/16 x 9/32	ALUM 6061	22	4.72	503	8802	38.61	15.6	C	S,M
80	3/16 x 9/32	ALUM 6061	18	4.72	503	8802	38.61	15.5	C	S
81	3/16 x 9/32	ALUM 6061	18	4.72	503	8802	38.61	14.1	-	-
82	3/16 x 9/32	STN 409	22	4.72	503	8802	38.61	19.9	C	S
83	3/16 x 9/32	STN 409	22	4.72	503	8802	38.61	19.9	C	S
84	3/16 x 9/32	STN 409	16	4.72	503	8802	38.61	17.5	C	S
85	3/16 x 9/32	STN 304 L	22	4.72	503	8802	38.61	29.9	C	S
86	3/16 x 9/32	STN 304 L	18	4.72	503	8802	38.61	23.5	C	S
87	3/16 x 9/32	STN 304 L	16	4.72	503	8802	38.61	25.3	C	S
88	3/16 x 9/32	STN 316 L	22	4.72	503	8802	38.61	26.5	C	S
89	3/16 x 9/32	STN 316 L	18	4.72	503	8802	38.61	27.3	C	S
90	3/16 x 9/32	STN 316 L	16	4.72	503	8802	38.61	16.1	C	S