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INSERTS MOLDED INTO STRUCTURAL FOAM: A LOOK AT THEIR STRENGTH

by

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CONTENTS

INTRODUCTION

The polyurethanes processed through Reaction Injection Molding (RIM) span a wide range of mechanical properties and find their way in many and varied applications. The characteristics of such parts are large projected areas and intricate designs. Both are made possible by the injection of reactive liquid mixtures into the mold. Structural foam is produced by foaming the liquid and relying on the expansion of the mix to fill the mold after injection. The chemistry of urethanes then allows the full range of flexural moduli to be covered from rigids to elastomers. With structural foam, parts will have larger cross sections and demonstrate a composite structure. A thin dense skin covers the outer surfaces while the core is light and microcellular.

Typical applications among others of foamed structural urethanes include computer and instrument housings. In some cases, these are multi-component assemblies which offer a challenge in the design of an efficient fastener. The hurdles to overcome are assembly-disassembly cycles, sufficient mechanical strength and a reasonable cost. This should include the cost of the fastener itself and also take into account the additional handling throughout the whole fabrication process (1). However, molded-in inserts offer the possibility of being integrated with the robotization programs of the molding operations. The technique is successful as evidenced by the production of a public phone housing with polyurethane structural foam and incorporating sixty-five molded-in inserts (2).

Little information however is available on the properties of inserts molded into polyurethane structural foam. In a recent monograph every aspect of integral skin polyurethane structural foam is extensively covered but scant attention is given to the strength of molded-in inserts (3). Specially designed screws for the use with plastics in general along with inserts used in post-molding situations are also described in a book reviewing the fastening of plastics (4). Inserts molded into thermoplastics are also discussed and concern is given to shrinkage of the resin causing delayed cracking. With thermoset structural foam obtained via liquid injection, these stresses should be greatly relieved.

The work presented here examines the molded-in insert as a fastening device. Standard screws offer a basis for comparison of the strengths attainable in assemblies of polyurethane structural foam. Then, the mechanical properties of a series of standard inserts available on the market are measured and discussed. These observations bring a contribution to the understanding of the behavior of inserts molded into thermoset polyurethane structural foam. Some insert design criteria are also discussed and should help in making the best choice for a particular application amongst those available.

EXPERIMENTAL

The mold

The mold (figure 1) consists essentially of a base and cover, both traversed by heating and cooling channels. The base contains two modules, one for the sprue and gate, the other for the rib. This offers the possibility of changing these sections completely without any major machining operations. The overall design including the sprue and rib was refined according to established standards (5). The machining was executed out of aluminum (6061 T-6) in our shop.

A cross section of the rib is shown in figure 2. At the bottom of the cavity lies an aluminum plate which serves to hold metal or plastic pins used to position the inserts or to mold pilot holes. This plaque also doubles as an ejector since air pressure can be applied to it through the underside of the mold. Overall the molded part measures 18 X 12 X 0.25 inches and has a 15 X 1 X 0.875 inch rib two inches from one side. Its volume is 63.6 in^3 (1041.8 cm^3) ignoring the drafts and sprue (18.6 cm^3). The mold is handled on a table which has one inclinable plane. Experiments with two planes of inclination determined that this offered no improvement in the filling characteristics of the mold.

A routine injection is performed as follows: The mold is closed and the six bolts are tightened. The plane is positioned at 30^o upwards in the direction of flow and the mold injected. After one minute, the mold is placed horizontally and the bolts are removed. Air pressure is then applied to the bottom of the mold releasing the plaque and cover. The plaque can then be pulled from the mold and the aluminum plate removed from the top of the rib.

Materials and Processing

A standard two component RIM system designed for structural foam was used throughout. The molded properties of the material are given in table 1 along with the processing conditions.

All molding operations were accomplished on an Accuratio Micro RRIM II machine fitted with a Kraus Maffei MK 10 mixhead. The machine uses reciprocating cylinders and parts were injected at 270 g/s. Injection times were varied to attain the desired molded densities.

Two types of fasteners were examined: screws and brass inserts. The screws had the standard A-B thread for wood or metal. Three diameters and three lengths were considered, table 2. Of the wide range of inserts available, only a few representative types were chosen and are available from various sources. The configuration and dimensions of these inserts are shown in table 3.

Testing Procedures

The principles for evaluating the performance of fasteners in plastics are somewhat obvious. Essentially, they consist of applying pulling (axial) or torsional (radial) forces to the device. The sophistication enters when quality instrumentation is used in the evaluation of these forces (4).

Three tests were performed on the inserts studied here: the pullout force measured in kilograms or pounds and the stripping and jackout torques measured in inch pound or newton meter. The gist of the methods is shown in figure 3.

Pullout forces were measured on an Instron using a special jig to hold the trimmed rib and with a 10-32 threaded adapter to pull on the insert. The head speed in all measurements was 10 mm/min.

The device to measure torques was built with a 15 in. press-drill having a low friction mechanism. The driven pulley was removed and the axel was fitted with an adapter for the torque wrench. The chuck was fitted with a hex-driver to transmit the torque via a screw to the insert. The torque wrench was a Williams MTD-2-75 with a 0-75 in. lb. scale.

To prevent tangential acceleration when the insert first lets go, which leads to erroneous torque values, the handle of the torque wrench is extended with a flexible arm. The force applied on the insert is then more uniform.

Jackout torques were measured using a thrust bearing as sketched in figure 3 to minimize frictional losses. The screw was also lubricated as it has been suggested previously (6).

RESULTS AND DISCUSSION

Screws

The holding power of screws was examined through one parameter, the pullout force (PO). The types of screws used are described in table 2. In all cases, the PO increases as the density of the molded urethane increases (figures 4,5,6,7).

For screws inserted in punched starter holes, an increase in the screw length at constant diameter (figure 4) or an increase in the screw diameter (figure 5), leads to an increase in the PO. Comparing these graphs, it is seen that no great improvement in the strength of an assembly can be attained by changing the screw diameter. At a density of 0.6 g/cm^3, going from a #6 to #10 screw will increase the holding power by 25 kg.

Similarly, comparing figures 6 and 7, the replacement of a #8 screw by a #10 in a molded hole will strengthen the assembly by about 25 kg. On the other hand, at the same density, using a one inch screw instead of a 5/8 inch will afford an increase of 115 kg.

Molded holes offer greater strength compared to drilled holes. This is to be expected since the screw threads are sunk into the harder and denser skin lining the molded hole. This finding is expressed in figures 6 and 7. At a density of 0.6g/cm^3, a #8 screw inserted in a molded hole rather than a drilled hole of the same diameter affords an increase of 35 kg. in the pullout force. For a #10

Inserts

1) Pullout force vs molded density

The pullout force for an insert increases with the molded density. These results are depicted in figure 8. The forces attained are comparable to those attained with a one inch #10 screw. This is remarkable considering the relatively small size of the insert (table 3). The same trend with increasing density of the molded part is observed for other inserts. The test values in table 4 for other inserts pertain to a $0.6 g/cm^3$ molded density.

2) Pullout forces vs position on the rib

Each plaque had four equally spaced (7.5 cm, center to center) inserts molded into the rib. The tests on each of the inserts were numbered from 1 to 4, 1 being closest to the gate and 4 the furthest in the direction of the flow. On the average, the strengths increased along the rib going in the direction of flow in the mold. In spite of the scatter and the variation from rib to rib, the effect is consistent as can be examined in figure 9. The pullout forces of insert A are measured on four ribs for densities 0.4 and 0.5 g/cm^3 and on three ribs for density 0.6 g/cm^3. The results for each position on one rib are connected by a line.

How could this effect best be explained? Firstly, we measured the density gradient in the direction of flow along the rib. We found that for a molded density of 0.5 g/cm^3 it was 0.518 g/cm^3 near positions 1 and 2. At position 3, it was 0.517 g/cm^3 and dropped to 0.505 g/cm^3 near position 4. Such a gradient is expected and because it is lower near position 4 and constant near positions 1 to 3, the cause does not lie here. The mechanical properties of the matrix along the rib increase from position 1 to 4. The results of the tensile tests performed on the plaques confirm this. Tensile strengths are consistently higher at the far end of the plaque from the injection point. Furthermore, it is possible that the temperature of the polymerizing mix at the moment it flows around the insert may play a role in the quality of the adhesion. Under this assumption, position 1 would have a lower contact temperature compared to position 4, and the higher temperature provides better wetting and thus better adhesion.

3) Insert configuration and the axial strength of the assembly.

For inserts A and B the results of pullout (PO) force and jackout torque (JOT) are given in table 4. Three molded densities are covered whereas for the other inserts all the results pertain to a 0.6 g/cm^3 molded density.

If we take the PO values, four inserts stand out: A, B, E and F. F is not comparable here because the high value is attained through oversize. A, B and E have pull out forces of 258, 194 and 284 kg respectively. A common feature of these inserts is the greater number of chamfers which confer the high pullout strengths to the assemblies.

The design of these ridges also has an effect on the strength towards pullout. The ridges on insert B are beveled because it was designed for insertion into a pilot hole of a thermoplastic. The threads on insert F are also beveled in the downward direction but are perpendicular to the axis on the upper side of the thread. Both arrangements are meant to confer minimum insertion and maximum extraction forces. When the insert is molded into a structural foam, this reasoning may not apply. This can be seen in the two cases where the inserts B and F were molded in an inverted position in the rib. This leads to even higher values of the pullout force.

In order to explain the effect we would need to know more about the behavior of the matrix as the insert is being torn out of the rib. However, considering the design B and F, it would seem that during extraction, these inserts when inverted, exert a compressive force on the surrounding foam. A close examination of the interface between the inserts and the polyurethane matrix reveals that very little densification has occured there. The presence of a foamed compressible structure near the insert rather than a brittle skin layer could in principle lead to such a behavior. That is, a brittle interface would immediately snap leaving a more or less free passage to the advancing insert. This mechanism will be further discussed in a later section.

Inserts C and D could represent examples of the inappropriate choice considering the matrix they were used in. The first is an expansion insert and would find its best application with a tough high modulus material. In general, it also has favorable economics since it can be installed without special tools. When inserted in a slightly undersized hole, the threads close on themselves. Then, when the screw is introduced, the insert expands embedding its fine knurls in the walls of the pilot hole. Furthermore, in molded-in applications, the liquid penetrates the slots and the threads need to be retapped.

The insert D also would be more suited in applications with a tough polymer. With a brittle material, the single groove creates on extraction, a large damaged area lending a free passage for the remainder of the pullout.

The jackout torques (JOT) for inserts A to F are reported in table 4. As such, the test is simply another way of doing a pullout test, but only requiring the use of a torque-measuring device. The set-up as depicted in figure 3 is a means of translating a radially applied force into one applied axially on the insert. In principle, this is simple but one needs to take into account frictional losses which are not easy to evaluate. The simplest approach is to minimize friction by the use of a thrust bearing and through lubrication of the screw (6).

As a rule, a plot of PO vs JOT (figure 10) should afford a direct relation. This is observed for most of the data points. The extrapolation to zero pullout force (kg) then indicates the frictional losses. In the case of our best data we observe 3 in. lb. of torque that does not directly translate into pulling force.

4) Insert configuration and the radial strength of the assembly

The radial strength of an insert is evaluated by measuring the torque required to debond the insert from the polyurethane matrix. For a given insert, the stripping torque increases with the molded density as shown in figure 12 by curve 3.

A maximum number of vertical grooves along the side of an insert is the design feature to look for when high torque values are desired. This automatically eliminates inserts E and F. Under stripping torque conditions, both inserts fail by first debonding. Then, they penetrate into the rib because of their threaded design. The torque then builds up to a maximum when the rib snaps. Insert B is the next to let go at 54 in. lb. Its two knurled upper ridges offer medium holding power. The next higher stripping torque value is obtained by insert A at 63 in. lb. Here again, the design maximizes the asperities on a vertical axis.

Insert C is not comparable in these torque tests since it has two slots which fill with resin. In fact, this insert is not designed for molded-in applications. Also, because the matrix here does not have a sufficiently high tensile strength, failure under stripping torque conditions occurs by expansion of the insert and thread failure. An interesting design modification would be to have the slots not reaching the internal threads and also more depth in the knurl pattern since the pullout force is somewhat low for this insert under the present molding conditions.

With its simple design, insert D yields the highest value in stripping torque. But this represents a compromise since the extraction force is rather low (table 4).

The sharpness of the asperities on insert A are also important to insure adequate mechanical properties of the assembly. In one experiment, we reused these inserts after cleaning and observed lower stripping torque values (figure 11, curve 2). Although care was taken not to damage the asperities on the inserts by using a brass brush, it would seem that extremely clean and sharp corners are a prerequisite for ultimate strength.

Out of curiosity, a set of samples of the A insert which had been subjected to stripping torques were then also tested for pullout force. The values found are plotted in figure 8. It is quite remarkable that these assemblies which were damaged radially still afford pull out strengths comparable to non stripped samples. Among the inserts examined, only the design of insert B would also afford such behavior. Insert D has the highest stripping torque value of all but the damage created by stripping would possibly further lower an already weak pullout force.

5) The extraction curve as an insert signature

A set of curves of pullout force vs displacement are compared in figure 12. The intensities should not be compared since the force scales are not consistent. It can be seen readily that each insert has its own signature. Similar configurations will have similar extraction traces and consequently similar assembly damaging mechanisms.

The curves of extraction force vs displacement for inserts F inv., F and E have a sharp peak at the beginning. The magnitude of this peak represents the force required for the debonding of the insert with the matrix. If it stands out from the mass of the extraction curve, the insert can actually be heard to snap. As it is being further removed from the matrix, the ridges compress the surrounding polymer again affording an increase in the extraction force. A maximum is reached, higher than the first failure force, after which the retaining force slowly decreases. It is this maximum we report here. Rigorously however, it is the value for the first peak that is important since it would correspond to the first loosening of the assembled parts. The displacement from the matrix is already 1.15 mm. at this point for inserts E and F. At 1.75 mm. displacement, both inserts let go completely.

Similar considerations can be held for the other curves of figure 12 and it can be added that they are highly reproducible. For instance, a set of seven traces for insert C were analysed and the peak ratios remained constant throughout.

A change in the molded density of the matrix was not found to affect these signatures to a large extent (figure 13). If the tearing out mechanism remains the same, only the intensities and positions of the relevant peaks should change. Thus only the total area under the curve would increase with increasing densities.

The extraction curve of the stripped sample of insert A is also instructive (figure 13). Here we see that although radial damage has occured, the insert still behaves according to the same tear out mechanism as the non stripped samples. This would be a desirable design feature in any insert. It is doubtful however, that a design could be suggested where axial damage would not entail a deterioration of the radial strength also.

Should an insert be subjected to severe axial stresses and if a certain amount of loosening is permitted, the best way to evaluate its capabilities is by measuring the area under the pullout curves. This area is proportional to the work of extraction. These values for the different inserts are given in table 5 and are also plotted versus the maximum extraction force in figure 14.

Because of their size relative to the other inserts, both F and F inv. stand out. Similar maxima are offered by B inv. and E for the extraction force, but B inv. is much more tenacious towards total failure. Finally, inserts A, B, C and D are comparable in their resistance to extraction and only the maximum force at which they begin to let go is their mark of distinction.

CONCLUSION

A set of standard brass inserts for thermoplastics were molded into polyurethane structural foam and found to afford remarkable mechanical properties in the assemblies.

Axial stresses applied by pulling on the insert or via the jackout torque test gave interesting results. These allow us to determine which insert design is best suited for an application in the particular structural foam.

The interpretation of the extraction curves for these inserts also helped us put forth a mechanism for the tearing out of inserts from a compressible foam.

ACKNOWLEDGEMENTS

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REFERENCES

1) J.M. Crate, Molded-in Inserts: Precautions and Guidelines, Plastics Design Forum, 6 (Nov., Dec.) 61 (1981).

2) E. Galli, 65 Inserts in RIM Phone Housing, Plastics Design Forum, 9 (Mar., Apr.) 63 (1984).

3) G. Klepek, "Konstruiren mit PUR-Integral Hartschaumstof" Carl Hanser Vergalg München 1980.

4) B. Lincoln, K.J. Gomes, J.F. Braden, "Mechanical Fastening of Plastics", Marcel Dekker, N.Y., 1984, p. 144.

5) Mobay Chemical Corp., Mold Design Manual (RM-8108(2)E), Part Design Manual (12/77(3)3).

6) J.R. Peddycord, Metal Inserts in Thermoplastic Foams, Journal of Cellular Plastics, 17, 274 (1981).

FIGURE AND TABLE CAPTIONS

Figure 1 Schematic of the mold without its cover.

Figure 2 Cross section of the rib cavity.

Table 1 Properties of the RIM sytem used.

Table 2 Screws used in the pullout tests.

Table 3 Description of the inserts used.

Figure 3 Schematic of the setups for the insert tests.

Figure 4 Pullout force as a function of density and screw length for a #10 screw (punched starter hole).

Figure 5 Pullout force as a function of screw diameter for a 5/8 inch screw (punched starter hole).

Figure 6 Pullout force as a function of density for a #8, 5/8 inch screw, comparison of a drilled hole versus a molded hole. 1: drilled hole 3.25mm; 2: molded hole 3.25mm.

Figure 7 Pullout force as a function of density for a #10, 5/8 inch screw, comparison of a drilled versus a molded hole. 1: drilled hole 3.25mm; 2: molded hole 3.25mm.

TABLE I

PROPERTIES OF THE RIM SYSTEM

Molded Parameters:	
Thickness (in.)	0.5
Density (pcf[g/cm^3])	37 (0.6)
Flex. Mod. (psi [MPa])	150,000 (1035)
Elongation at break (%)	3
Molded Conditions:	
Visc. (cps @ 77°F)	A 200
	B 1400
Ratio A/B	1.17
Component temp (°F[°C])	80-85 (27-29)
Gel time (sec)	36-40
Mold Temp (°F[°C])	130-150 (54-66)

TABLE 4

COMPARISON OF INSERT CONFIGURATION AND THE MECHANICAL PROPERTIES OF THE ASSEMBLY

– PO: pullout; JOT: jackout torque; ST: stripping torque.

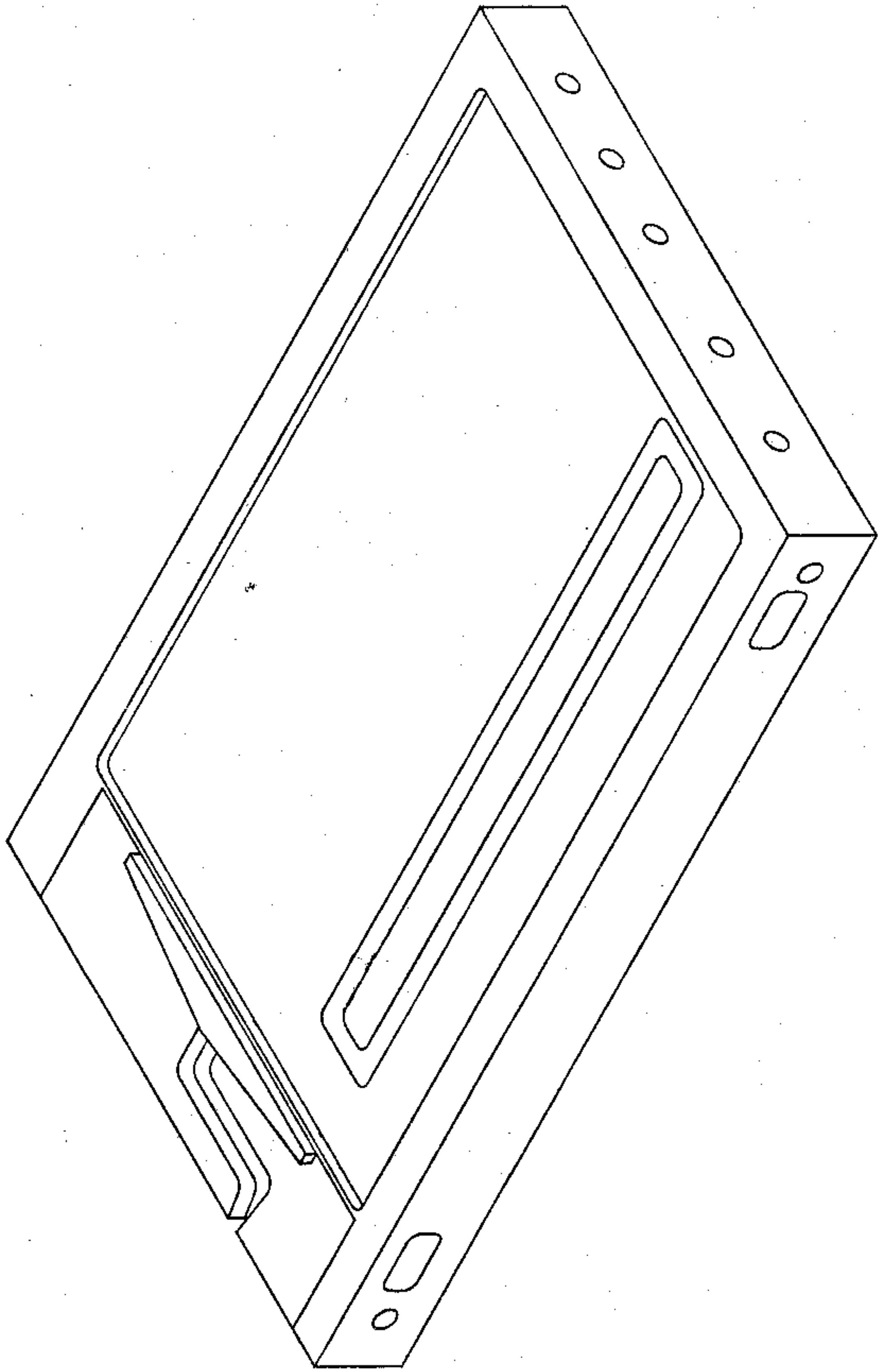
Type	Prop.	Molded Density (g/cm$^{\times}$)		
		0.6	0.5	0.4
A	PO (kg)	258	164	99
	JOT (inlb/Nm)	14/1.58	10/1.13	7/0.79
	ST (inlb/Nm)	63/7.12	65/5.09	27/3.05
B	PO (kg)	194 (312 inverted)		
	JOT (inlb/Nm)	17/2.03		
	ST (inlb/Nm)	54/6.10		
C	PO (kg)	162		
	JOT (inlb/Nm)	13/1.47		
	ST (inlb/Nm)	64/7.23		
D	PO (kg)	132		
	JOT (inlb/Nm)	10/1.13		
	ST (inlb/Nm)	74/8.36		
E	PO (kg)	284		
	JOT (inlb/Nm)	15/1.70		
	ST (inlb/Nm)	29/3.28		
F	PO (kg)	587 (733 inverted)		
	JOT (inlb/Nm)	26/2.94		
	ST (inlb/Nm)	46/5.20		

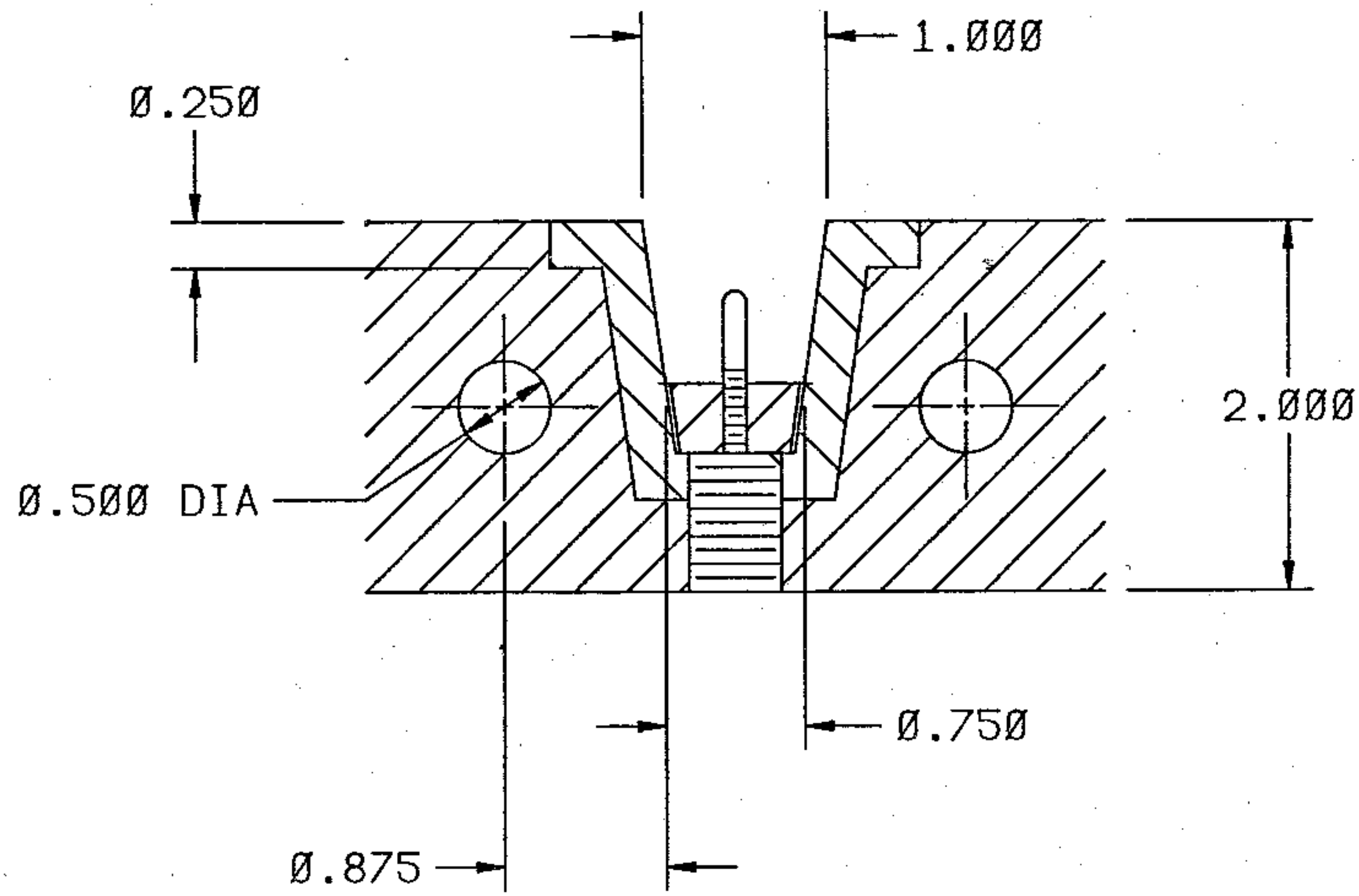
TABLE 5

COMPARISON OF INSERT CONFIGURATION AND WORK OF EXTRACTION AT 0.6 g/cm× DENSITY

Type	Work of Extraction	Max. Extraction Force (kg)
A	3.50	258
B	3.51	194
B inv	9.26	312
C	2.58	162
D	3.10	132
E	5.19	284
F	10.26	587
F inv	18.14	733

fig 1





1.000
Ø.250
2.000
Ø.500 DIA
Ø.750
Ø.875

TABLE I

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Flex. Mod. (psi [MPa])	150,000 (1035)
Elongation at break (%)	3

Molded Conditions:

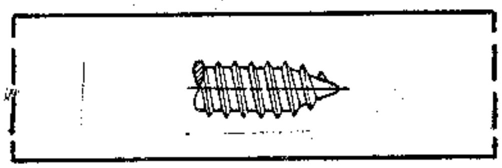
Visc. (cps @ 77°F)	A 200
	B 1400
Ratio A/B	1.17
Component temp (°F [°C])	80-85 (27-29)
Gel time (sec)	36-40
Mold Temp (°F [°C])	130-150 (54-66)

TABLE 2

SCREWS USED IN PULLOUT TEST

Type:

A - AB



NO:		6	8	10
Length	(in.)	5/8	5/8	5/8, 3/4, 1
Int. dia.	(in.)	0.105	0.122	0.143
	(mm)	2.66	3.10	3.63
Ext. dia.	(in.)	0.138	0.167	0.187
	(mm)	3.50	4.24	4.75

TABLE 3

DESCRIPTION OF INSERTS USED

- all inserts are in brass, except D in steel
- internal threads are 10-32
- diameter (D) and length (L) in inches
- relative size depicted is not respected

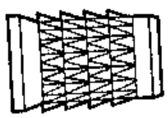
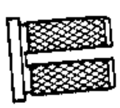
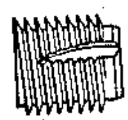
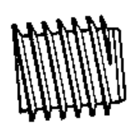
Type	Configuration	
A		D: 0.280 L: 0.395
B		D: 0.278 L: 0.375
C		D: 0.262 L: 0.375
D		D: 0.25 L: 0.375
E		D: 9/32 L: 0.375
F		D: 7/16 L: 0.500

fig 3

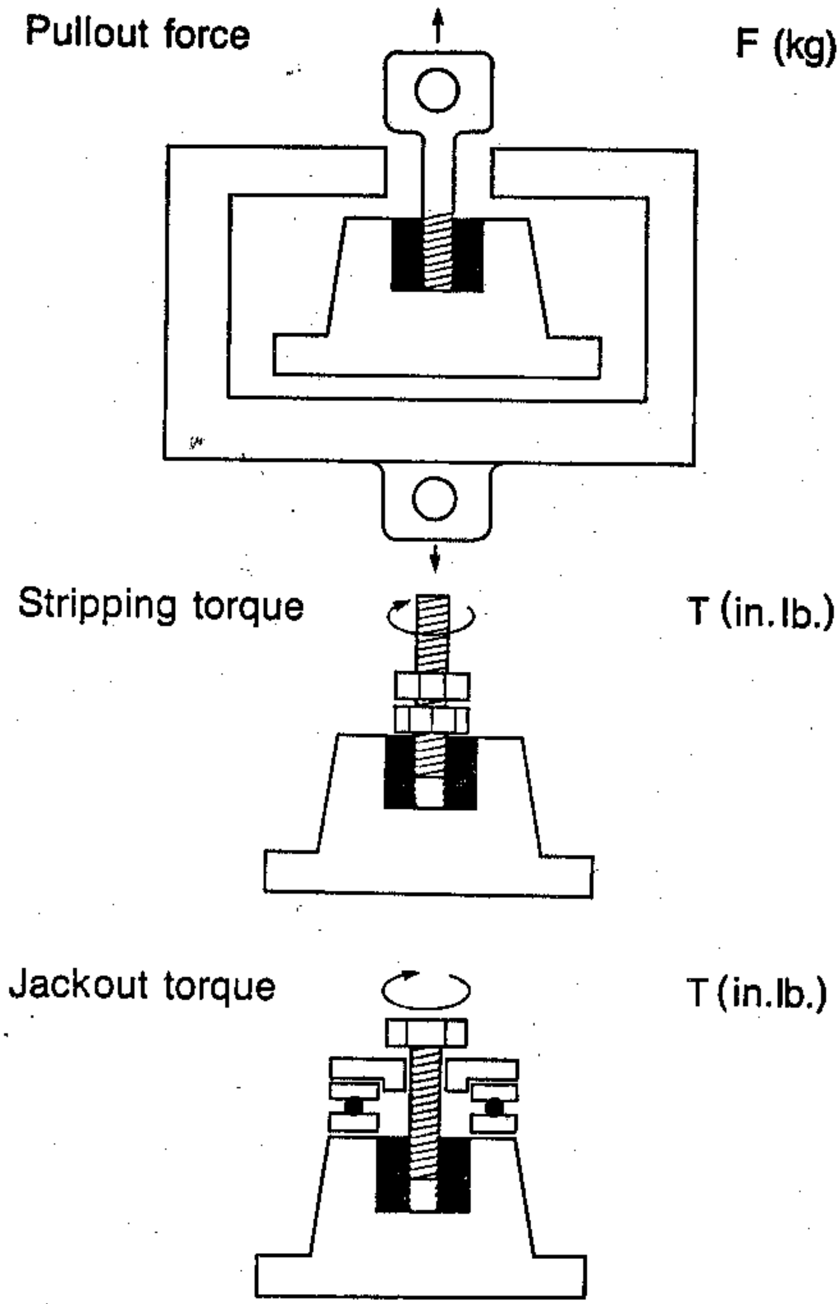

Pullout force
F (kg)
Stripping torque
T (in.lb.)
Jackout torque
T (in.lb.)

fig 4

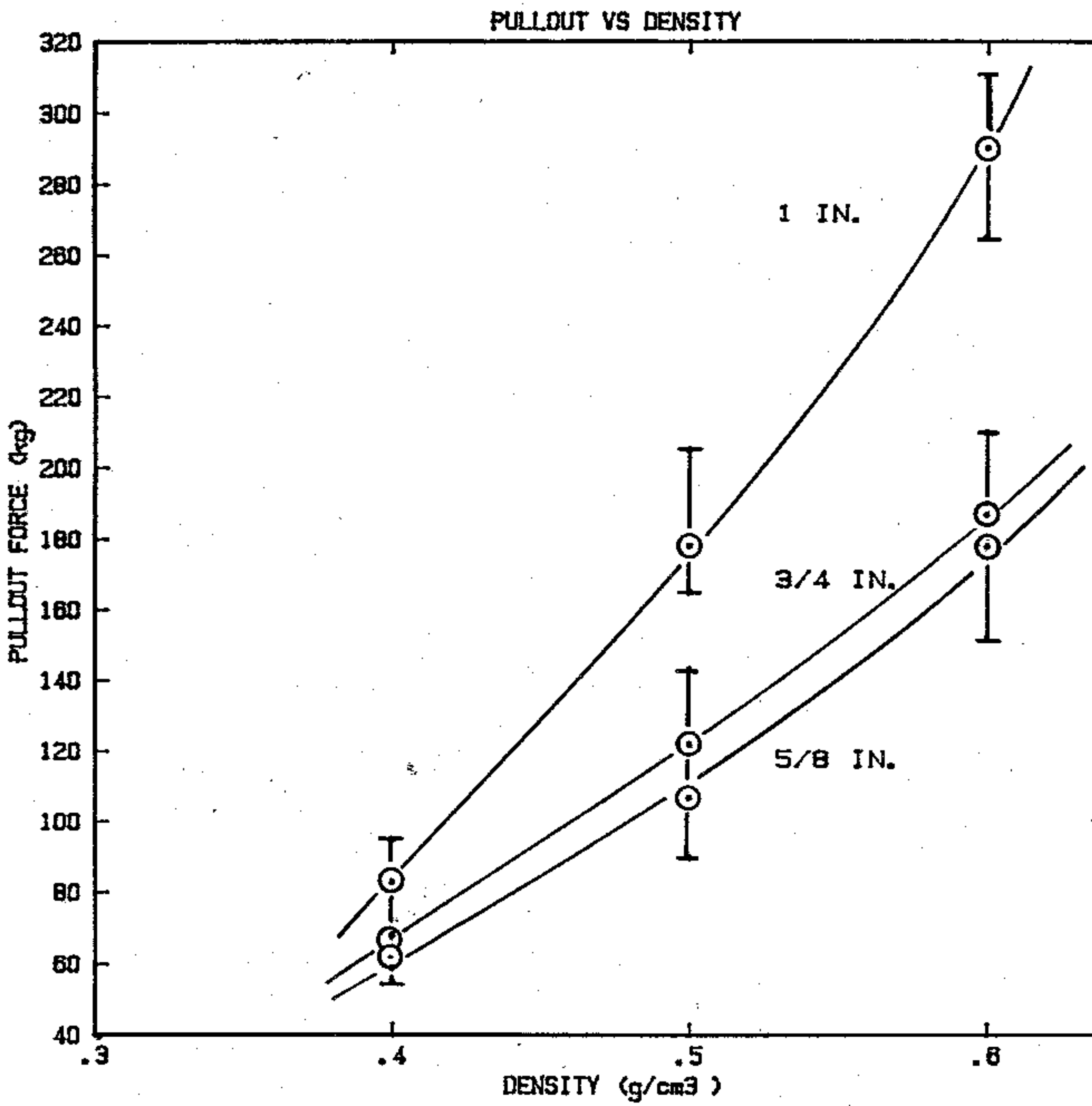
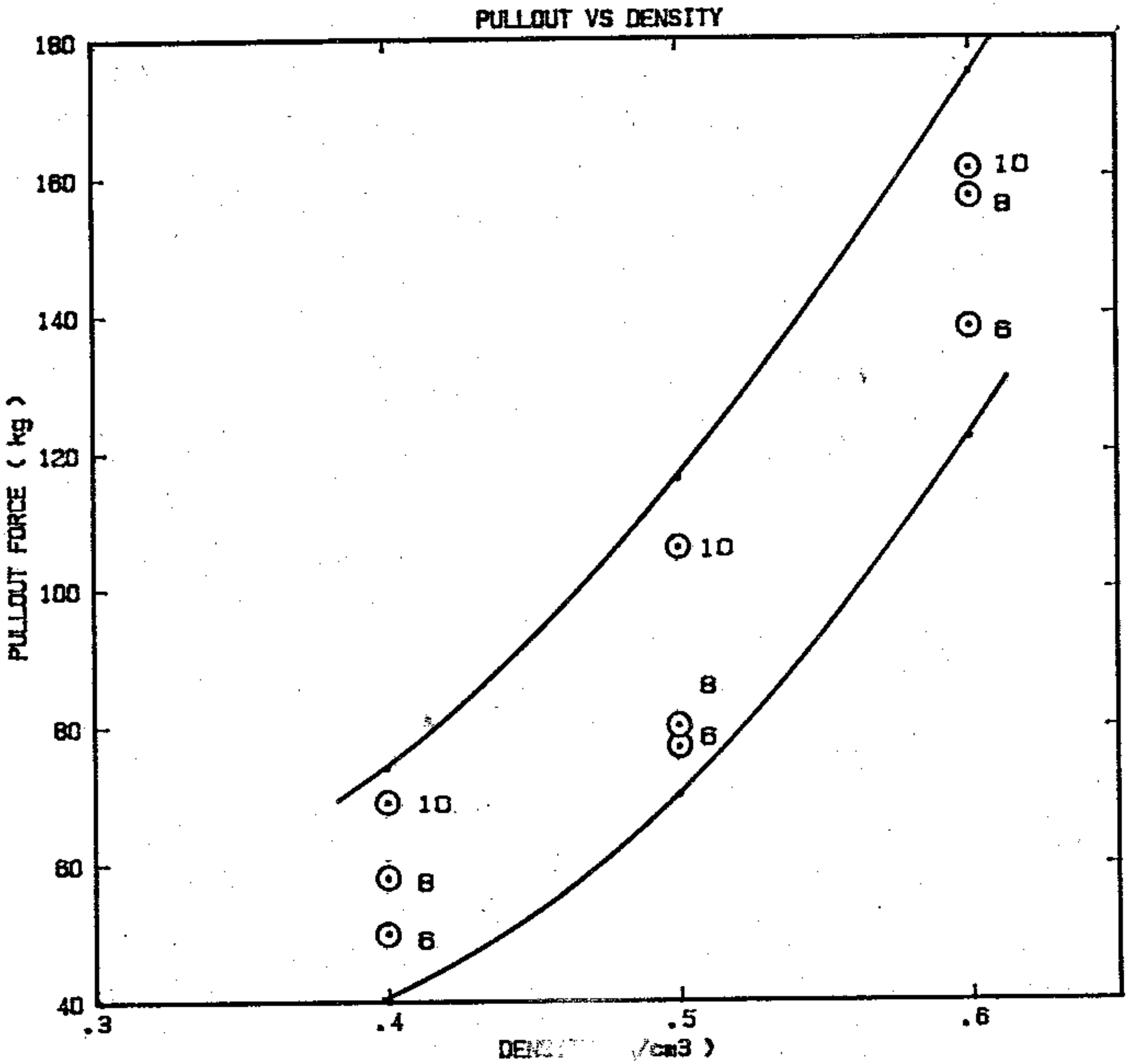

PULLOUT VS DENSITY
PULLOUT FORCE (kg)
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
.3
.4
.5
.6
DENSITY (g/cm3)
1 IN.
3/4 IN.
5/8 IN.

Fig 5



PULLOUT VS DENSITY
PULLOUT FORCE (kg)
180
160
140
120
100
80
60
40
.3
.4
.5
.6
10
8
6

fig 6
JK

PULLOUT VS DENSITY

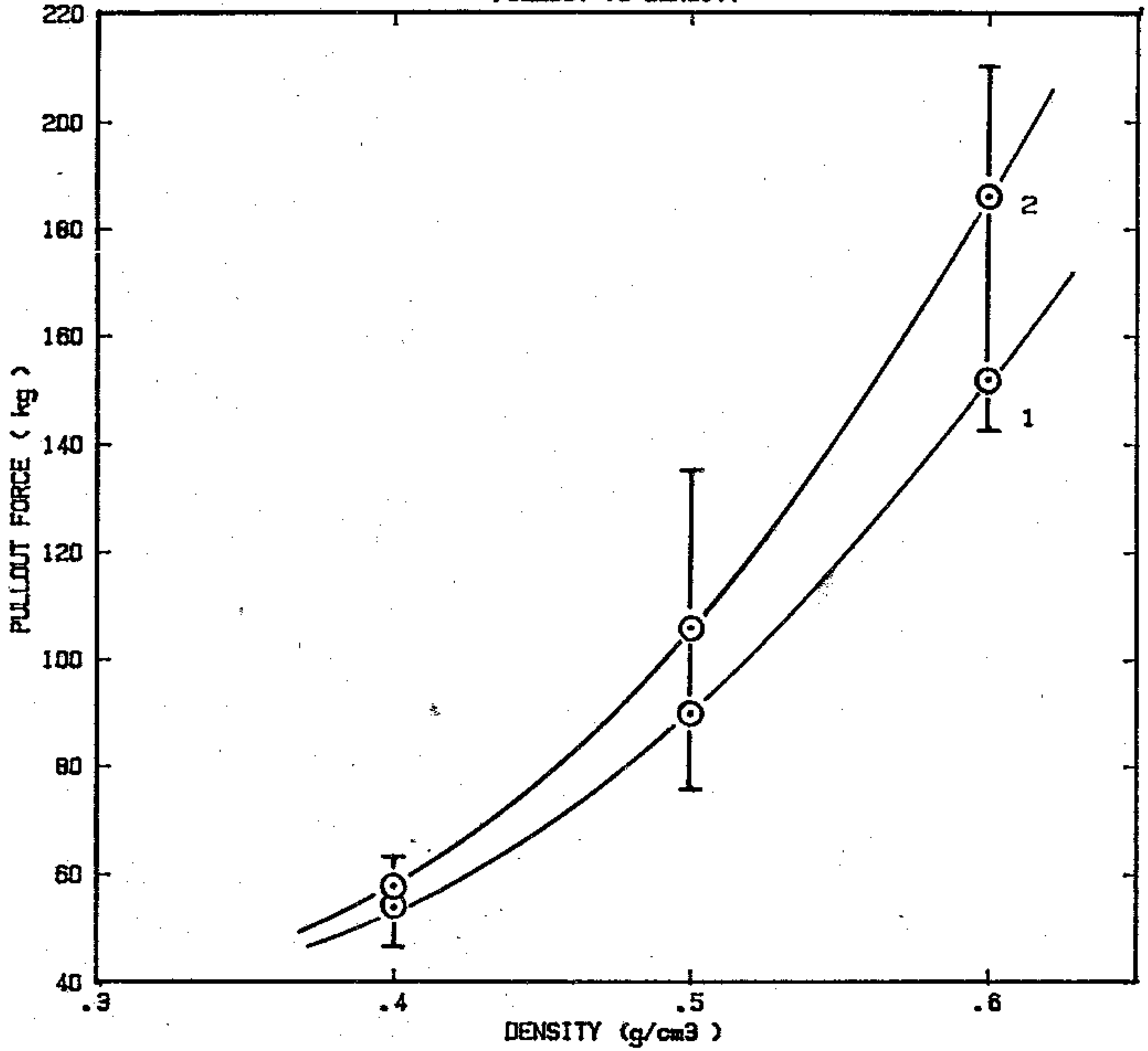
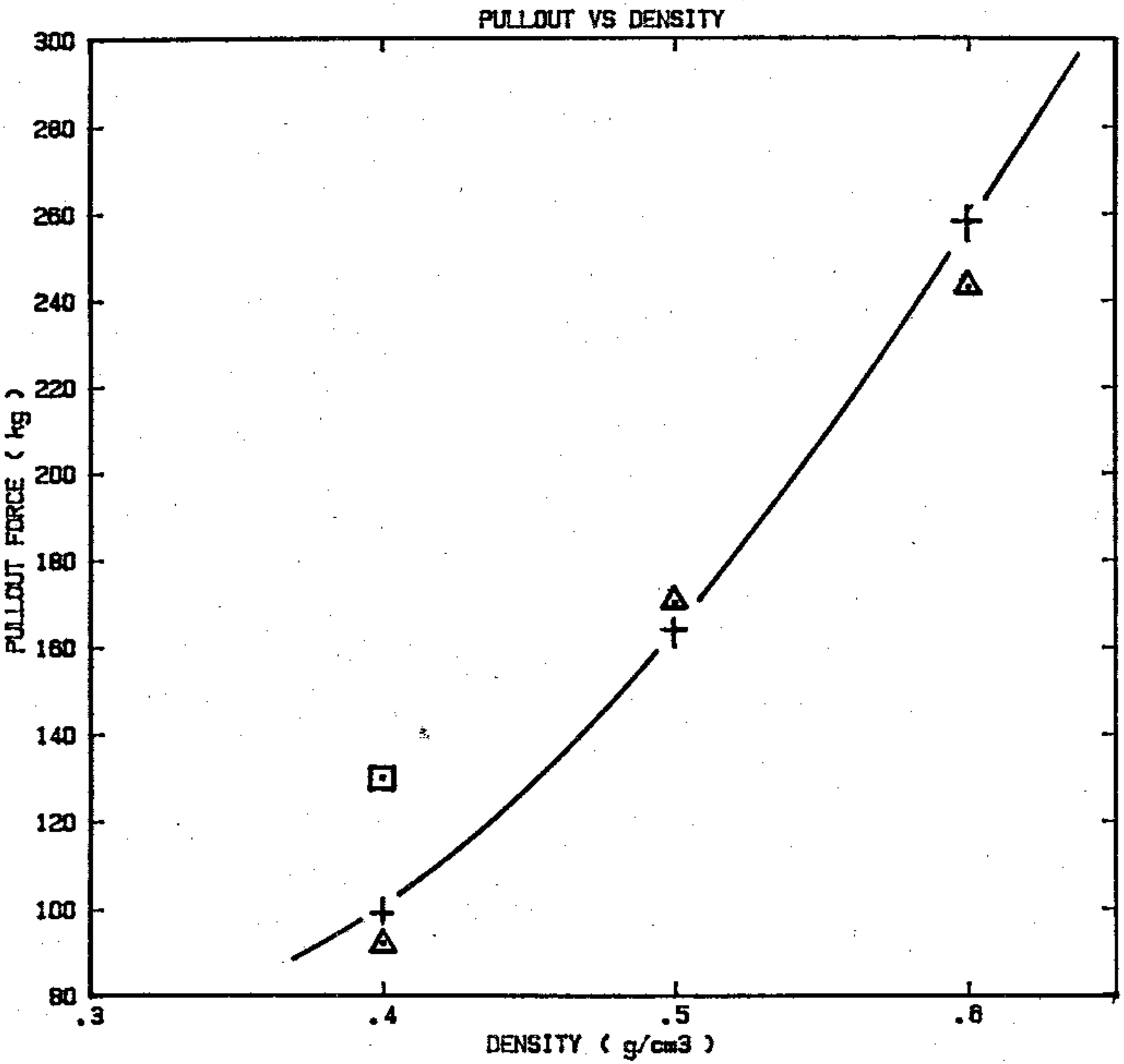


Fig 8



PULLOUT VS DENSITY
PULLOUT FORCE (kg)
300
280
260
240
220
200
180
160
140
120
100
80
.3
.4
.5
.6
DENSITY (g/cm3)

TABLE 4

COMPARISON OF INSERT CONFIGURATION AND THE MECHANICAL PROPERTIES OF THE ASSEMBLY

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Type	Prop.	Molded Density (g/cm^3) 0.6	0.5	0.4
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	JOT (inlb/Nm)	10/1.13		
	ST (inlb/Nm)	74/8.36		
E	PO (kg)	284		
	JOT (inlb/Nm)	15/1.70		
	ST (inlb/Nm)	29/3.28		
F	PO (kg)	587 (733 inverted)		
	JOT (inlb/Nm)	26/2.94		
	ST (inlb/Nm)	46/5.20		

fig 9

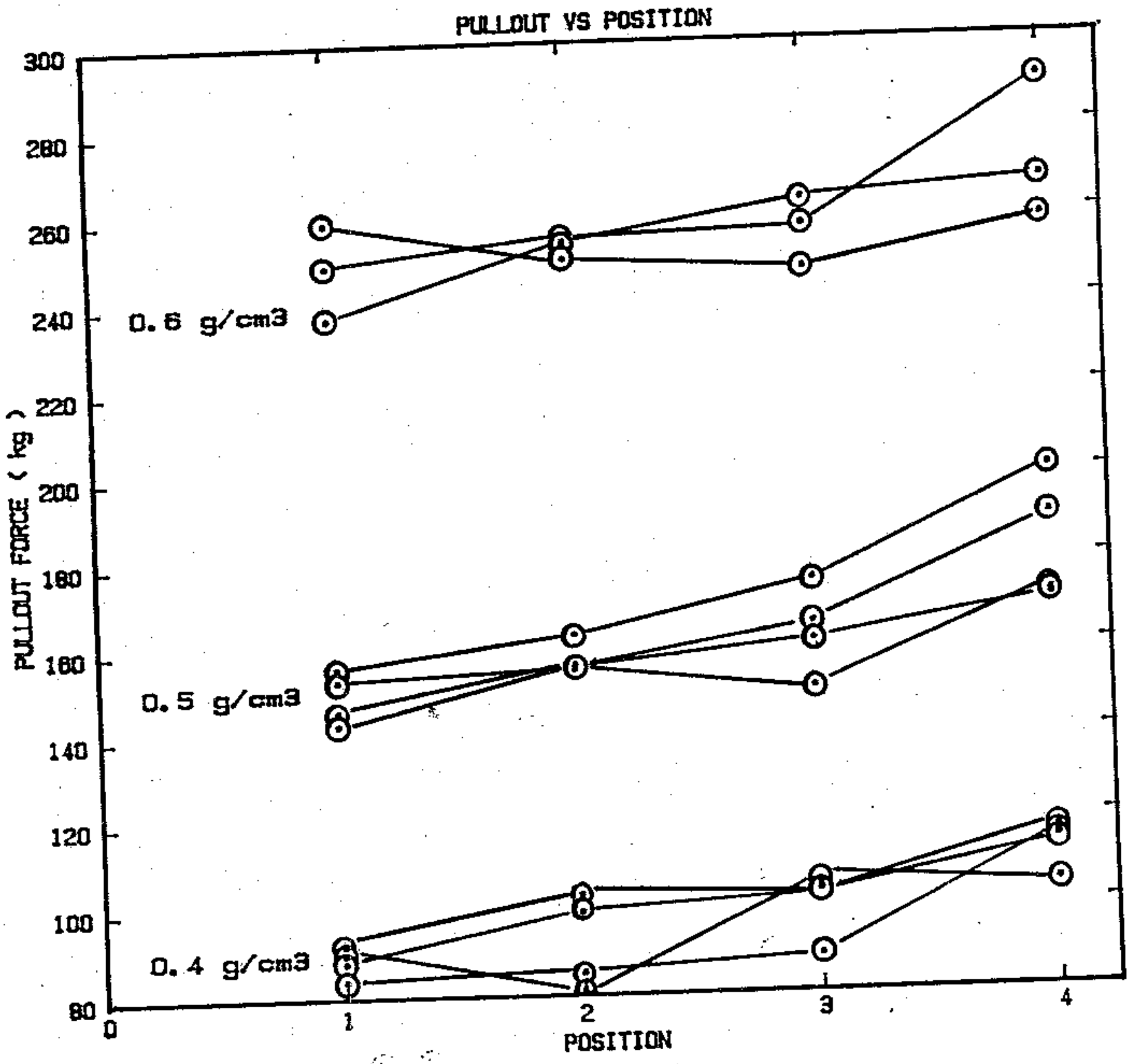
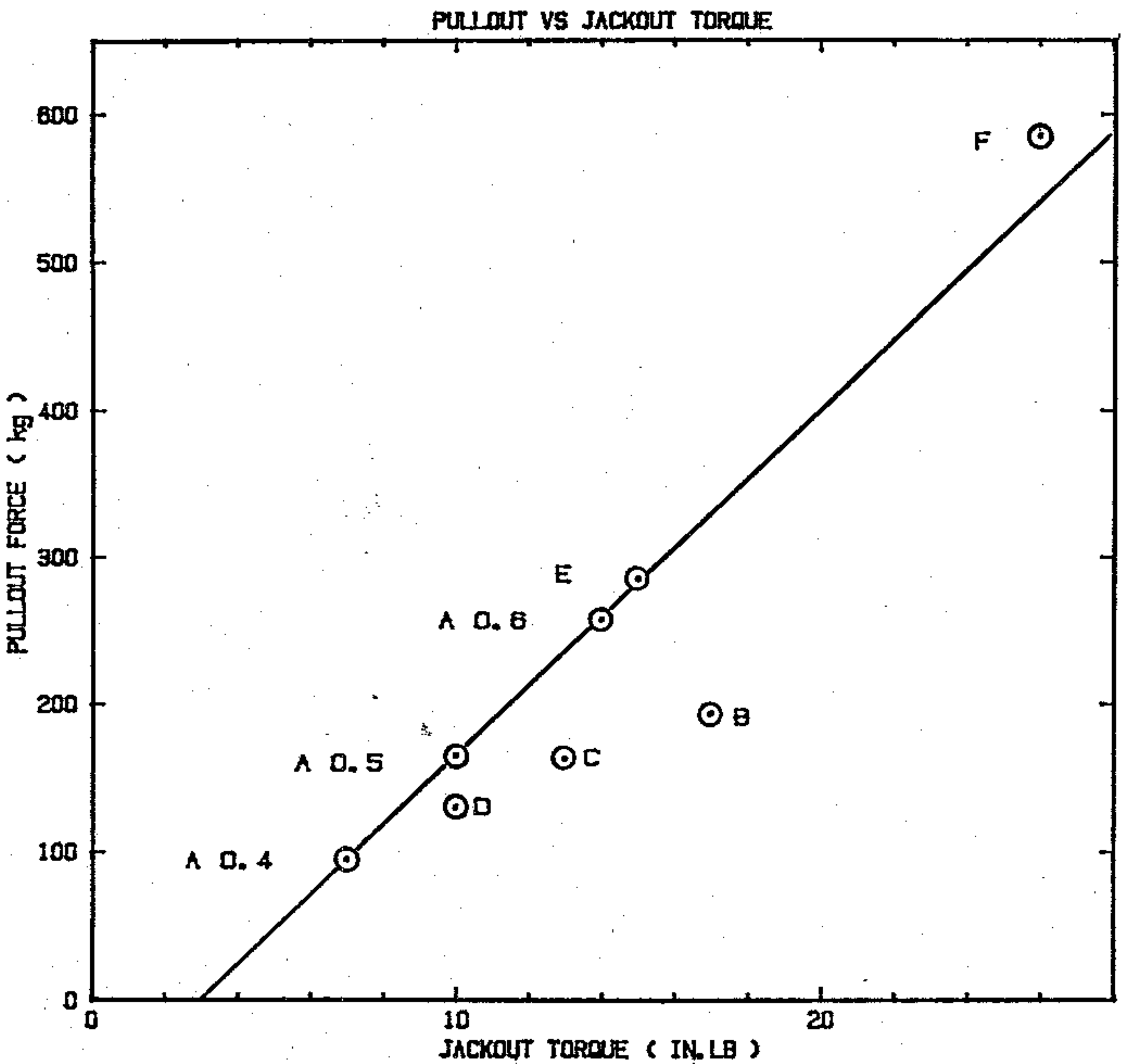

PULLOUT VS POSITION
PULLOUT FORCE (kg)
300
280
260
240
220
200
180
160
140
120
100
80
0
1
2
3
4
POSITION
0.6 g/cm3
0.5 g/cm3
0.4 g/cm3

fig 10



PULLOUT VS JACKOUT TORQUE
PULLOUT FORCE (kg)
0
100
200
300
400
500
600
0
10
20
JACKOUT TORQUE (IN.LB)
A 0.4
A 0.5
A 0.6
E
D
C
B
F

fig 4

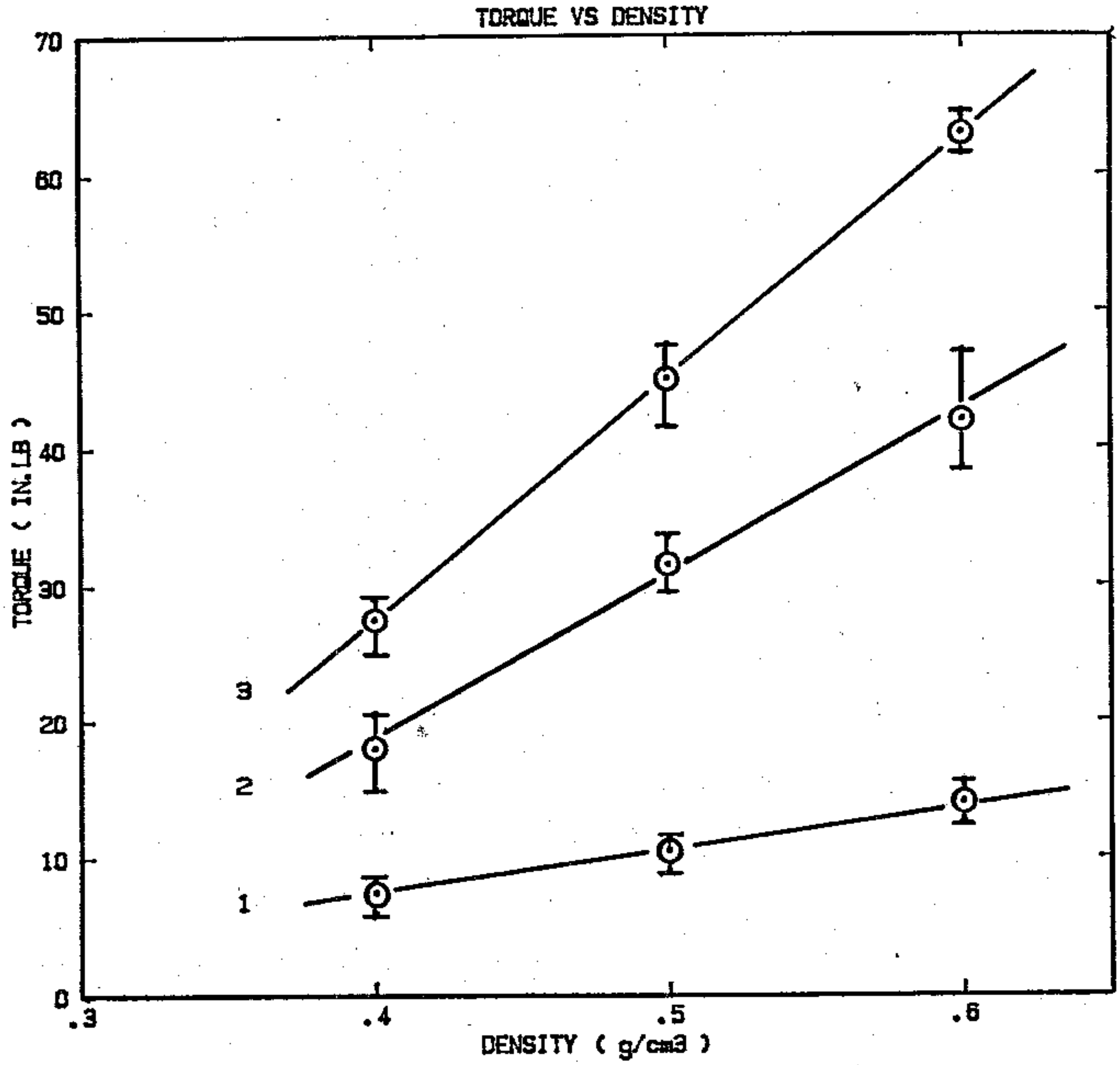
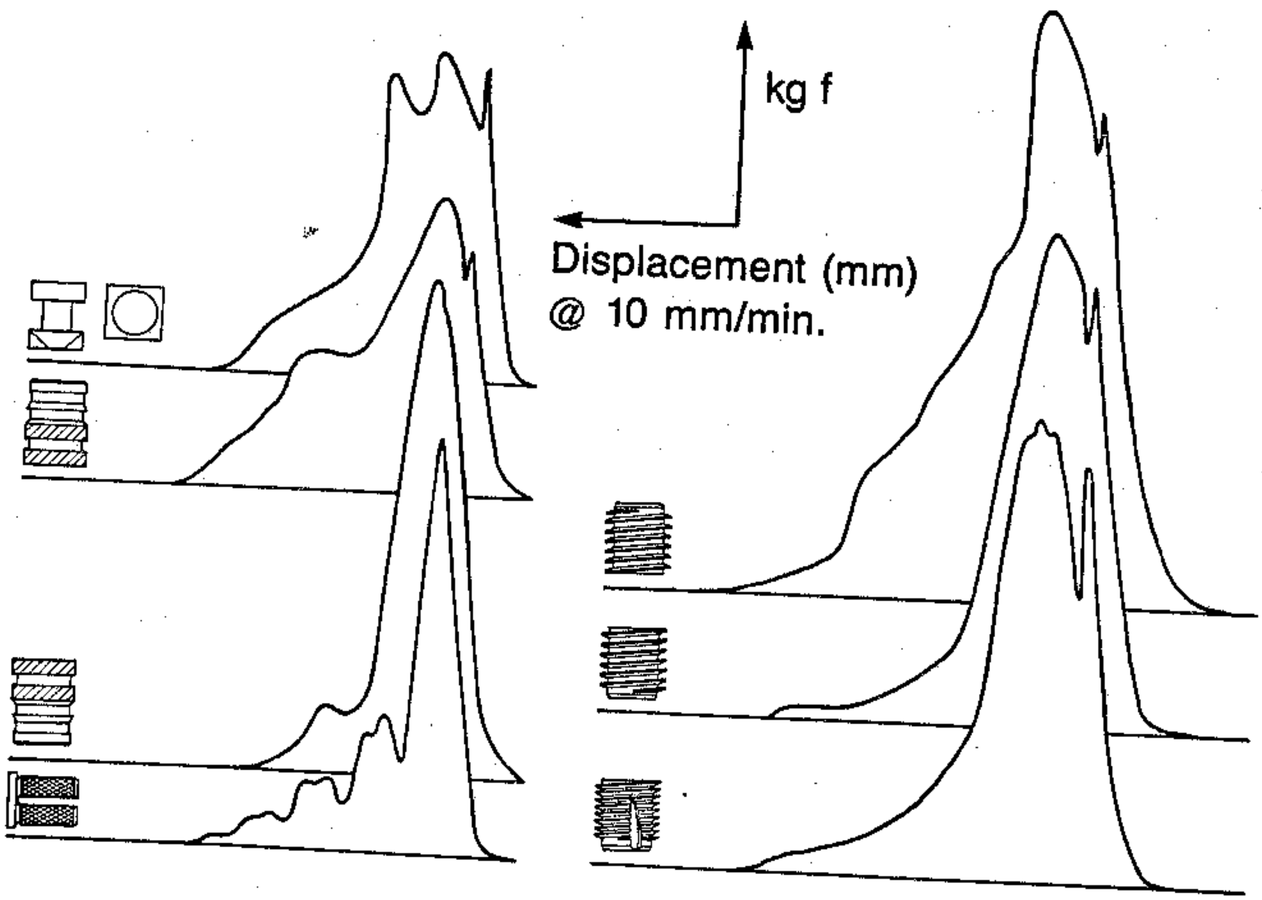

TORQUE VS DENSITY
TORQUE (IN.LB)
0
10
20
30
40
50
60
70
.3
.4
.5
.6
DENSITY (g/cm3)
1
2
3

Fig 12



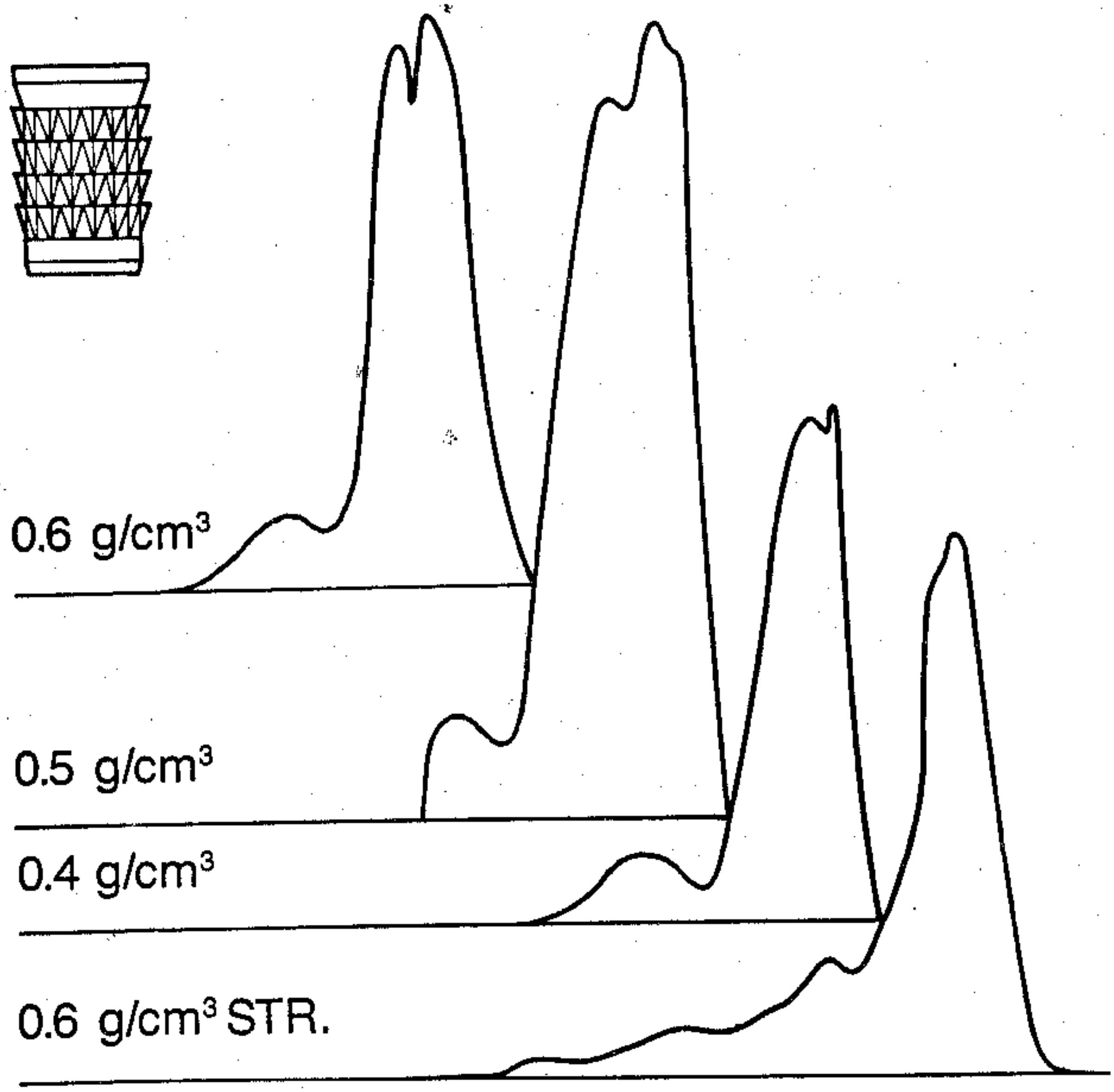
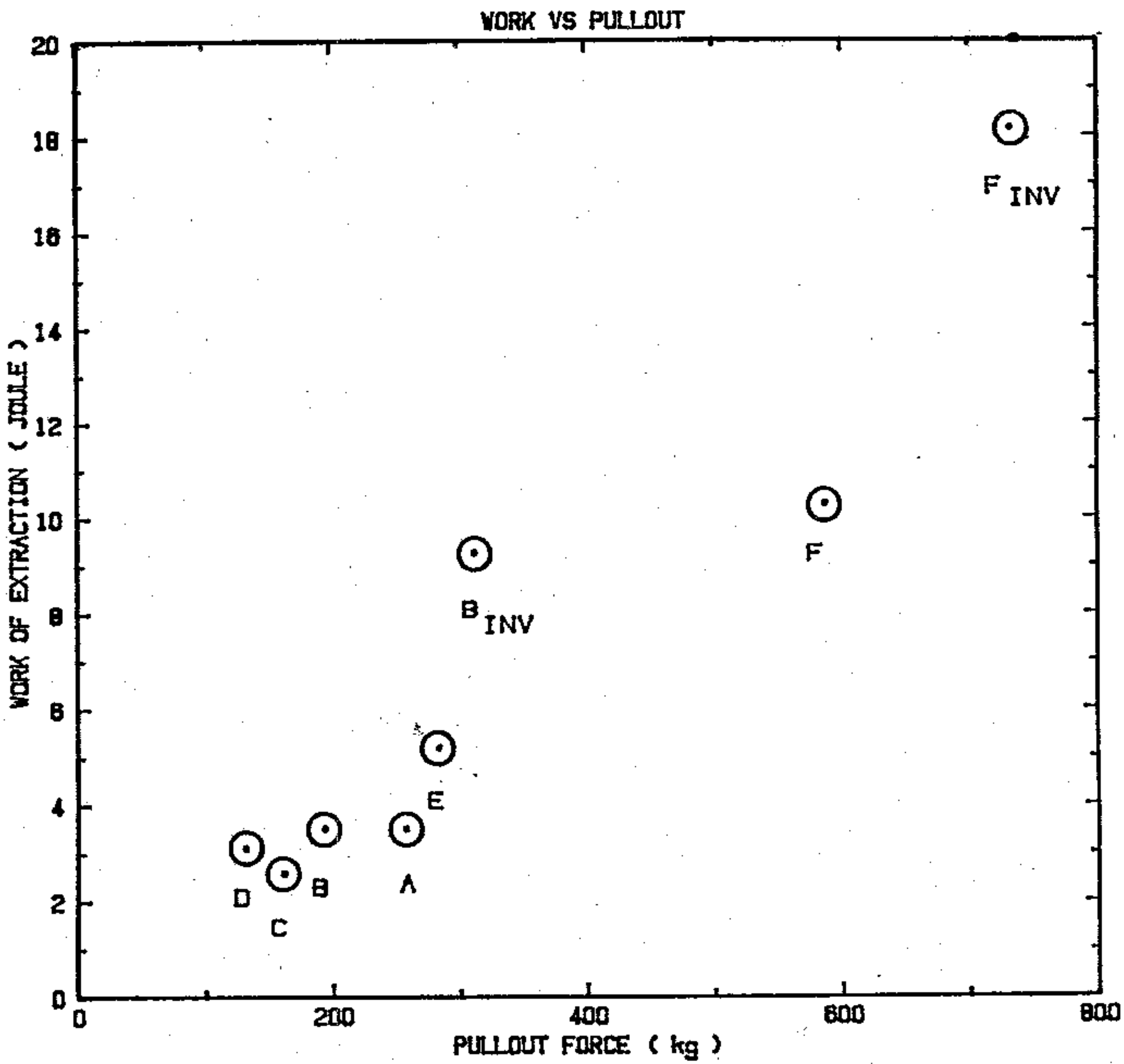

0.6 g/cm3
0.5 g/cm3
0.4 g/cm3
0.6 g/cm3 STR.

TABLE 5

COMPARISON OF INSERT CONFIGURATION AND WORK OF EXTRACTION AT 0.6 g/cm^3 DENSITY

Type	Work of Extraction	Max. Extraction Force (kg)
A	3.50	258
B	3.51	194
B inv	9.26	312
C	2.58	162
D	3.10	132
E	5.19	284
F	10.26	587
F inv	18.14	733

fig 17


WORK VS PULLOUT
WORK OF EXTRACTION (JOULE)
PULLOUT FORCE (kg)
0
2
4
6
8
10
12
14
16
18
20
200
400
600
800
D
C
B
A
E
B INV
F
F INV