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Drop Tests of 325 Pound 6M Specification Packages

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ABSTRACT

Testing of 6M specification packages, performed in response to concerns over the integrity of the clamp-ring closure, showed that the clamp-ring was unable to retain the top in thirty foot drop tests of packages having the maximum allowed weight (290 kg or 640 lb). To determine if the clamp-ring closure was adequate for packages with lower contents weight, a series of tests were performed on packages weighing 147 kg (325 lb) at a range of impact angles. The results showed that the standard clamp-ring closure was unable to retain the top in tests of standard 6M packages weighing 147 kg (325 lb). A test employing a plywood disk enhanced closure with impact at 6.5º retained its top successfully.

BACKGROUND

The results of tests of maximum weight, 55 gal. drum sized 6M packages, performed to study the performance of conventional clamp-ring closures, showed that the clamp-ring was unable to retain the top in 9 m (30 ft) drop tests (Reference 1 and 2). However, 6M packages seldom approach this maximum weight and lighter packages less vulnerable to Hypothetical Accident Condition (HAC) performance tests. To clarify this issue, a series of tests were performed to determine the performance of the conventional clamp-ring closure of 6M packages with a representative weight of 147 kg (325 lb).

TEST PROGRAM

The objective of the test program was to determine the ability of standard clamp-ring closures (of 6M Specification Packages weighing 147 kg) to withstand HAC drop tests at various impact angles. Ten 6M Specification Packages were obtained from a manufacturer regularly involved in the production of 6M packages, and ballasted to 147 kg (325 lb).

Earlier tests of drum type packages have shown that the Center-of-Gravity-Over-Corner (CGOC) orientation and the Shallow Angle orientation challenge the closure in different ways. The impact angles for the tests were selected to capture the range of responses. To accomplish this, HAC drop tests were planned for 10º, 20º, 30º, 45º and Center-of-Gravity-Over-Corner (CGOC) orientations. The test plan called for a repeat of any test which resulted in a failure of the closure. Provision was made in the test plan for performing tests with the plywood disk enhancement, for cases where the standard package failed. The 55 gallon drum size 6M package was chosen as the representative case for these tests and to be consistent with the previous testing.

Following the pattern of earlier testing of packages with clamp-ring closures, each test was preceded by a Normal Conditions of Transport (NCT) test from a height of 1.2 m (4 ft). The preconditioning tests were planned to challenge the drum's lock ring closure arrangement so that the effects of the subsequent 9 m (30 ft) drop would be maximized. The target point for each NCT drop was located 90 degrees, circumferentially, from the target point for the HAC drops. The planned program is shown in Table 1.

The acceptance criterion for the performance or the overpack was that the lid be retained in such a way that a significant reduction in effectiveness of the overpack did not occur.

Table 1. Drop Test Conditions

325 LB 6M TEST MATRIX[C]	
All test packages subjected to NCT and HAC tests.	
Test	Orientation
325-5	10°, Shallow Angle
325-4	20° Impact Angle
325-3	20° Impact Angle (Repeat Test)
325-6, Plywood Disk	20° Target Angle (6.5° Actual Impact Angle)
325-2	30° Impact Angle
325-1	55° (CGOC)
325-7, Plywood Disk	30°
325-8, Plywood Disk	55° (CGOC)

PROCEDURE AND FACILITY

The drop tests were performed in the SRS drop test facility. The test sequence consisted of a 1.2 m (4 ft) NCT preconditioning drop, a 9 m (30 ft) HAC drop. The NCT drop was conducted at the Center of Gravity Over Corner (CGOC) for all cases. The point of contact for the NCT drop was 135º clockwise from the drum seam. The point of contact for the HAC drop was 45º clockwise from the drum seam. Previous testing has shown that the HAC drop typically produces a buckle across the top having an angular width of around 90º. The orientations selected will cause this buckle to occur midway between the NCT and HAC contact points. In addition, the buckle will coincide with the clamp-ring closure bolt and lug assembly, so that the bolt and lug assembly is loaded in bending.

For each drop, the package was aligned to within one degree of its nominal orientation prior to the drop. Each drop was recorded at 1000 frames per second, using a high speed video camera, as well as normal speed video. Following each drop, the package was measured and photographed to document the extent of damage.

The drop test surface was constructed from a 15.9 cm (6.25 in.) thick armor plate, approximately 1.52 m (5 ft) square, anchored in a 76.2 cm (30 in.) thick reinforced concrete slab. The target slab is isolated from the concrete floor of the building. The target slab weighs approximately 7076 kg (15,600 lb), which is over 45 times the weight of the test packages (147 kg or 325 lb.).

TESTING

The 6M Closure drop tests began with the 10°, shallow angle test. The second 9 m drop was performed at 20° and resulted in a failure of the closure. In accordance with the test plan, the next (third) test was also performed at 20°, and resulted in a failure of the closure almost identical to the previous test. Following the test procedure, package 325-6 was prepared with the plywood disk enhancement and tested at 20° release angle. The package drifted during the drop, striking at an impact angle of 6.5°. The enhanced package successfully retained its top when subjected to the 9 m (30 ft) drop.

The planned test sequence was completed with tests at 30° and 55° (CGOC). Two additonal tests were conducted with plywood disk enhanced closures, at 30° and at 55° (CGOC).

With the exception of 325-6, the impact angles for the other packages were within 3° of their release angles, except for 325-2, which drifted by 5°.

RESULTS

The NCT preconditioning tests typically resulted in minor damage, confined to the neighborhood of the point of impact. The NCT drops were all in the CGOC orientation and resulted in the top of the package being bent downward about 8 mm at the point of impact.

10° Shallow Angle 9 m Drop Test for 325-5

The 9 m 10° drop resulted in nearly uniform flattening of the side of the package, the flat region having a width of approximately 28 cm (11 in.). The inverted "J" rim of the top was bent inward, forming a reverse curvature. The curl of the drum was flattened, with the clamp-ring remaining engaged with the curl. The vertical dimensions of the package were essentially unchanged. The damage was typical of very shallow angle drops, with the deformation of the chime being comparable to that of the curl. The clamp-ring remained engaged with the drum and top and the top was securely retained. The results of this drop are shown in Figure 1.

20° Impact Angle 9 m Drop Test for 325-4

The 9 m 20° drop resulted in separation of the top and flattening of the rim and closure ring of the package at the point of contact, and associated flattening (about 28 cm) along the length of the drum. The height of the package was not changed. The damage was typical of low angle drops, with a distinct triangular, flattened region surrounding the point of contact, and local buckling of the drum and top in the damage

region. The rim of the top was bent downward resulting in the top pulling out from under the closure ring on both ends of the flattened region. These openings then propagated around the lid, so that it became disengaged from the clamp-ring and the drum over its most of its circumference (approximately 230°). The maximum opening between the top and the curl of the drum, measured after the test, was approximately 8.9 cm (3.5 in.). The raised and curved (inverted "J") rim of the top was buckled inward and folded downward, almost touching the horizontal, disk section of the top, at the point of impact. The top was barely retained on the package. The results of this drop are shown in Figure 2.

Repeat 20° Impact Angle Tests of Package 325-3

The test procedure specified that a repeat test be performed following any test which resulted in a failure. Accordingly, following the top failure of the 20° drop of package 325-4, a duplicate test was performed using package 325-3.

The 9 m 20° impact angle drop yielded results were almost identical with those of 325-4, which was also dropped at 20°. As in the case of 325-4, the drop resulted in separation of the top and flattening of the rim and closure ring of the package at the point of contact, and associated flattening along the length of the drum. As in the case of 325-4, the damage was typical of low angle drops, with a distinct triangular, flattened region surrounding the point of contact, and local buckling of the drum and top in the damage region. The rim of the top was bent downward along a line parallel to the flattened side, resulting in the top pulling out from under the closure ring on both ends of the flattened region. These openings then propagated around the lid, so that it became disengaged from the clamp-ring and the drum over approximately 190° of its circumference. The maximum opening between the top and the curl of the drum, measured after the test, was approximately 6.35 cm (2.5 in.). The raised and curved (inverted "J") rim of the top was buckled inward and folded downward, on to the horizontal, disk section of the top, at the point of impact. As in the case of 325-4, the top was barely retained on the package. The results of this drop are shown in Figures 3 and 4.

Tests of Package 325-6 (Plywood Disk Enhanced Closure, 20° Impact Angle)

The test procedure specified that a test with the Plywood Disk Enhanced Closure be preformed following any event where a repeat test resulted in a second failure. Accordingly, following the second failure in the 20° drop (package 325-3), a duplicate (20° drop) test of a package with a Plywood Disk Enhanced Closure was performed using package 325-6. This enhancement consisted of replacing the top 2.54 cm (1 in.) of Celotex with a 2.54 cm thick plywood disk. The results of the drop testing of package 325-6, are shown in Figures 5 and 6.

The plywood disk enhanced package was subjected to a CGOC NCT preconditioning drop, like that of the other test packages.

The 9 m 20° drop was performed with the package oriented so that its axis was 20°, top down, at release. Examination of the high speed video revealed that the orientation drifted following release, so that the angle of the drum at impact was 6.5º. The response of the package was sufficiently energetic that it rotated upright and came to rest standing on its bottom. The top remained securely attached following the test. The drop resulted in flattening of the rim and closure ring of the package at the point of contact, and associated flattening along the length of the drum. The height of the package on the impact side was reduced by 1.3 cm (½ in.). The damage was typical of low angle drops such 325-5 (which struck at 7°), with a distinct triangular, flattened region surrounding the point of contact, and local buckling of the drum and top in the damage region. The inverted "J" rim buckled inward to a greater extent on 325-6, and the adjacent region of the top buckled outward to a much greater extent than the corresponding deformations of 325-5. The clamp-ring remained engaged with the top and the curl of the drum around the full circumference except for the region of reverse curvature of the rim at the point of impact. At this location, the raised and curved (inverted "J") rim of the top was buckled inward against an upward bulge of the top. Unlike the previous cases, the curl of the drum also assumed a reverse curvature, so that a gap (of approximately 1.3 cm or ½ in.) was formed between the clamp ring and the curl and top of the drum at the impact point, Figure 19. The top was securely retained, with no opening into the interior (Celotex region) present. The results of this drop are shown in Figures 5 and 6.

30° Impact Angle 9 m Drop Test for 325-2

Package 325-2 (30° case) struck at 25° and resulted in separation of the top and flattening (about 28 cm wide) of the rim and closure ring of the package at the point of contact, and associated flattening along the length of the drum. The height of the drum on the impact side was reduced by 6 mm (¼ in.) The damage was typical of intermediate angle drops, with a distinct triangular, flattened region surrounding the point of contact, and local buckling of the drum and top in the damage region. The flattening of the side was less pronounced than in the shallow angle cases. As in the 20° test cases, the rim of the top was bent downward along a line parallel to the flattened side. This bending was more pronounced than in the 20° cases, and resulted in the top pulling out from under the closure ring on both ends of the flattened region produced by the 9 m drop. These openings then propagated around the lid, so that it became disengaged from the clamp-ring and the drum over its most of its circumference (approximately 250°). The maximum opening between the top and the curl of the drum, measured after the test, was approximately 11.4

cm (4.5 in.). The raised and curved (inverted "J") rim of the top was buckled inward and folded downward, on to the horizontal, disk section of the top, at the point of impact. As in the 20° cases, the top was barely retained on the package. The results of this drop are shown in Figure 7.

CGOC Impact Angle 9 m Drop Test for 325-1

Because of the additional 20° tests, the planned 45° test case was omitted. The 9 m 55° CGOC drop resulted in separation of the top and crushing of the "corner" of the package in the region of the point of contact. The height of the package, through the point of impact was reduced by approximately 8.3 cm (3 ¼ in.). The damage was typical of CG over corner drops with extensive local buckling and folding of the drum and top in the damage region. The crushing of the corner resulted in the top pulling out from under the closure ring in the NCT damage region. The opening then propagated around the lid, so that it became disengaged from the clamp-ring and the drum over approximately 120°. A discharge of dust occurred when the top began to separate from the drum, indicating that pressure caused by deformation of the drum was released by the opening of the top. The maximum opening between the top and the curl of the drum, measured after the test, was approximately 3.8 cm (1.5 in.) The results of this drop are shown in Figure 8.

Plywood Disk Enhanced Closure Tests

Following the initial series of 325 lb tests, two additional tests were performed with the plywood disk enhanced closure, at 30° and 55° (CGOC) orientations. As in the case of 325-6, the additional plywood disk enhanced packages were subjected to a CGOC NCT preconditioning drop, like that of the other test packages.

30° Impact Angle 30 Ft Drop Test for 325-7

The lid remained attached with no opening, following the impact, for the 9m 30° drop. The drop resulted in flattening of the rim and closure ring of the package at the point of contact, with associated flattening (about 30.5 cm wide) along the length of the drum. The height of the package on the impact side was reduced by 2 cm (3/4 in.). The damage was typical of intermediate angle drops, with a distinct triangular, flattened region surrounding the point of contact, and local buckling of the drum and top in the damage region. At impact, the drum rebounded and rotated, so that the second impact was on the chime flattening it and the lower rolling ring. As in the 20° test cases, the rim of the top was bent downward along a line parallel to the flattened side. This bending was more pronounced than in the 20° cases. The lower edge of the clamp ring was displaced about 1 cm (3/8 in.) in the vicinity of the NCT point of impact, exposing much of the bottom surface of the curl in this region. Although the engagement of the clamp ring with the curl of the drum was challenged , the drum lid was securely retained all around its circumference.. The raised and curved (inverted "J") rim of the top was buckled inward and folded downward, against the buckled section of the top at the point of impact, producing a reversed curvature. The closure ring was flattened in this region, and formed a chord across the reverse curvature section, resulting in disengagement of the ring from the top over a length of about 15 cm (6 in.) with a maximum gap width of about 1.6 cm 5/8 in.) The results of this drop are shown in Figure 9.

CGOC Impact Angle 30 Ft Drop Test for 325-8

On the rebound, from the 9m CGOC drop, the package rotated to the vertical position and came to rest standing on its bottom. As a result, there was no flattening of the side of the package away from the crushed corner. The drop resulted in separation of the top and crushing of the "corner" of the package in the region of the point of contact. The height of the package, through the point of impact, was reduced by approximately 7.3 cm (2 7/8 in.) The damage was typical of CG over corner drops with extensive local buckling and folding of the drum and top in the damage region. The crushing of the corner resulted in the top closure ring being pulled over the drum curl in the NCT damage region, exposing the plywood. The resulting opening was approximately 1.3 cm (½ in.) wide and 30.5 cm (12 in.) long, corresponding to an angular width of about 60°. The results of this drop are shown in Figure 10.

DISCUSSION

The objective of these tests was to determine if 6M packages loaded to typical weights were vulnerable to the same lid opening mechanism that was observed in tests of maximum weight 6M.

Although no gap size was set as a failure criterion, the results of earlier tests are useful guidelines for interpretation of marginal results. For example, occurrence of an opening 11.4 cm (4 1/2 in.) long and 1.43 cm (9/16 in.) high led to redesign and adoption of a bolted flange closure for the 9975. Development of a significant opening or complete loss of the top would make contents vulnerable to fire event. Consequently, the presence of such and opening is deemed a failure of the closure.

There are many factors which affect the performance of a drum closure during drop tests. Important test conditions are: weight of package, height of drop and angle of impact. Structural characteristics of the package determine its ability to withstand the test conditions imposed. These characteristics include: package diameter, shell material and thickness, strength of internal fill material (e.g., Celotex), and configuration of closure (clamp-ring, bolted flange, etc.). For the clamp-ring closure configuration, like that employed by the 6M, a study of published drop test results has shown that packages having a weight ratio of less than 50% were typically able to retain

their tops in HAC drop tests, Reference 3. Those having weight ratios greater than 50% typically failed.

The results of the present testing are shown in Figures 11 and 12, for the principal test conditions: Weight Ratio, Angle of Impact, and Drop Height. The present results are designated "6M, .45" or "6M, .45 Ply" in the legends on these figures. The figures provide views of a three dimensional pass-fail threshold surface in Weight Ratio, Impact Angle, and Drop Height space.

For the present testing, the packages were tested at 147 kg (325 lb), resulting in a weight ratio of 45%. Despite these test packages being below the 50% guideline, the drop tests resulted in large top openings for all cases except the 10°, shallow angle case. The two failures for the 20° case indicate that the failure threshold is closer to 10° than to 20°. Comparison of these results with the 9975 test results (References 4 and 5) suggests that the clamp-ring closure when employed on a 55 gal (drum size) package (22 1/2 in. in diameter) is less secure that when applied to a 35 gal package (18 ¼ in. in diameter).

In the tests reported here, the failure mechanism appears the same as in the earlier 6M tests. The opening of the top is attributed to the combination of load applied by bending of the top and closure ring with unloading of the ring due to deformation. The top is first observed to pullout from beneath the clamp-ring or the clamp ring to pull over the drum curl at one or both ends of the flattened region caused by the HAC drop. The opening then grows progressively and rapidly from the initial openings. In the 20° and 30° cases the opening propagated completely around the circumference of the top.

The Celotex disks in the 325 lb test packages did not show indication of the crushing and breakup in the central region that was observed in the 640 lb test packages. This indicates that loading of the closure due to translation of the contents was less of a factor in the opening of the top than in the 640 lb cases.

The pressurization of the interior of the package caused by volume change during impact is too low, to account for the opening of the top. However, the ejection of Celotex dust observed during the CGOC test of 325-1 confirms that the interior pressure is increased by the deformation of the package, and will contribute to the loading of the top.

The Plywood Disk enhancement had the objective of strengthening the closure radially, so that the clamp-ring would remain engaged with the curl of the drum and the top. The Plywood Disk enhanced package was dropped at 20° to determine if this simple enhancement would enable the package to retain its top, following the failure of the closure in the two 20 ° cases. However, the package drifted during the drop so that the impact angle was 6.5°. Since the standard clamp-ring closure performed successfully in the 10° test case, the successful performance of the plywood disk enhancement in this shallow angle impact is inconclusive.

Comparison of the packages for the cases tested here shows that the maximum opening was made in the 30° case. The results fell into three damage types, depending on impact angle. The shallow angle case resulted in flattening of the side of the package and reverse curvature of the rim at the point of impact. The mid angle cases resulted in large top openings, with modest corner crushing. The CGOC case resulted in significant corner crushing with a significant top opening.

CONCLUSION

The results of the testing showed that the standard clamp-ring closure was inadequate for 6M packages at weight typical of DOE shipments.

The 55 gal. drum size packages with standard clamp-ring closures are more vulnerable to HAC drop tests than similar 30 or 35 gal size packages.

For the 55 gal. drum size, the closure was typically most vulnerable to impact in the CGOC orientation.

REFERENCES

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Figure 1. Flattened side of 325-5 following 10°, shallow angle drop test. Damage is typical of results for shallow angle impact.

Figure 2. The 20° impact resulted in an opening of about 8.9 cm (3 ½ in.).

Figure 3. Package 325-3 in mid rebound following impact for 9 m (30 ft, 20° drop test. The opening of the package top is visible at this time.

Figure 4. Impact region deformation and top opening of 325-3 following repeat of 9 m (30 ft), 20° drop test.

Figure 5. Package 325-6 with plywood disk enhanced closure struck the test surface at 6.5°. The damage was typical of that for other shallow angle tests. As discussed in the text, the intended impact angle was 20°.

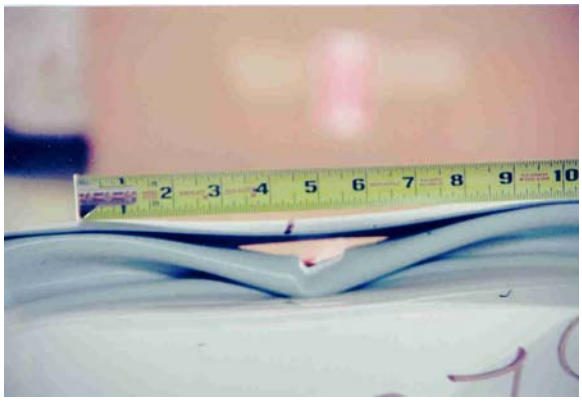

Figure 6. The test of 325-6 resulted in reverse curvature of both the drum curl and the inverted "J" rim of the top

Figure 7. Package 325-2 following 9 m (30 ft) drop with 30° impact angle. This test resulted in the largest opening of the top.

Figure 8. The 55°, CGOC test resulted in an opening of approximately 3.8 cm (1.5 in.).

Figure 9. Package 325-7, with plywood disk enhanced closure, successfully retained its lid in the 30 °, 9 m drop test.

Figure 10. The CGOC, 9 m drop test of package 325-8, with plywood disk enhanced closure, resulted in the opening shown here.

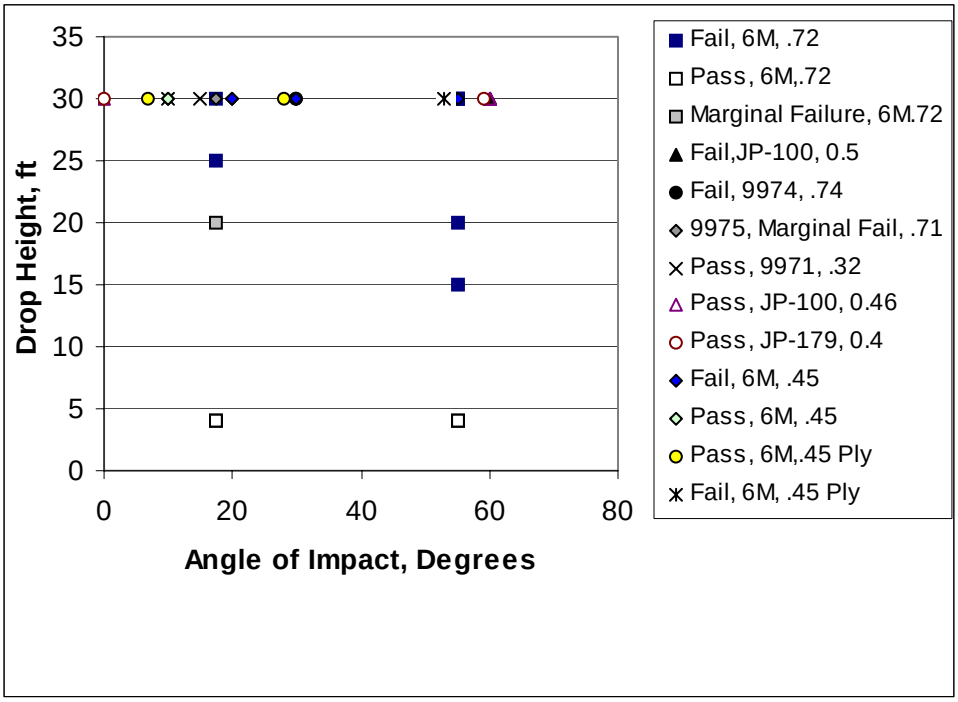

Figure 11. Top Retention in Clamp-Ring Closure Drop Tests.

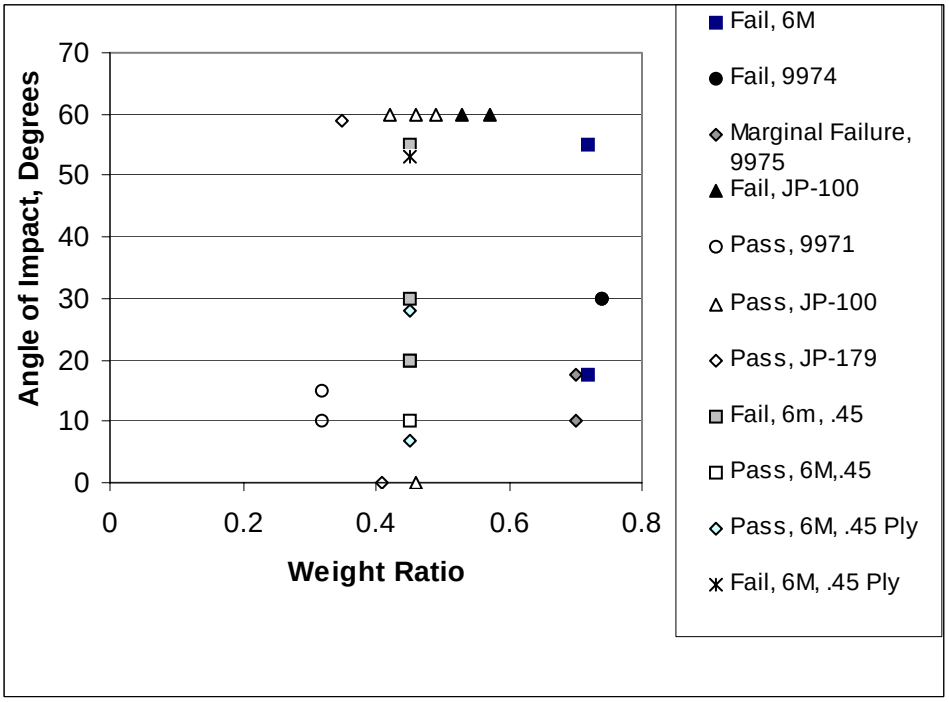

Figure 12. Top Retention in Clamp-Ring Closure Drop Tests from 9 m,.for Various Impact Angles