

## **Angular Variation of Vibration Weld Joint Strength : In Horizontal Plane and In Vertical Plane**

### **ABSTRACT**

Joint strength of a vibration welded parts is a critical parameter that determine the burst strength of a welded structure, like air intake manifolds. This paper presents experimental values of weld strengths that are slanted with respect to the clamping force direction (Vertical plane). It also presents local weld strengths of an in-plane, circular weld joint, as a function of its angular position relative to the welding head movement direction (Horizontal plane). Finally the paper shows significant discrepancy between the real part weld strength and typical laboratory strength data which is normally obtained from a flat bar welded in a butt-joint mode, and tested in pure tension mode.

### **INTRODUCTION**

Vibration welding process is widely applied in the manufacturing process for joining two or more components of consumer/industrial products. The process is particularly well suited for manufacturing automotive air intake manifolds, because it is fast, economical and fairly reliable. Application of the technology to plastic air intake manifolds has been well established in Europe and it finds increasing applications in North America and Asia.

One of the major issues of vibration welding process is its weak weld joint strength. Joint strength of two similar reinforce plastics part is only as high as that of the matrix of the material; for a 33% glass filled Nylon material, the weld joint strength is about half the strength of the parent material. Several workers have tried to maximize the joint strength through optimization of welding process, such as adjusting clamp pressure, melt-down, and vibration amplitude. The resulting improvement, using flat bar samples, was only 10% to 15%. (V. Kagan) However, in actual manifold burst experiments, it was shown (Lee,1998) that such process optimization can produce improvements in the range of 30% to 40%. It is not clear whether such dramatic improvement applies only to the specific manifold design, or can be reproduced other vibration welded pressure vessels, or air intake manifolds.

Weld strength is considered to change depending on the direction of welding: parallel or transverse. It is commonly held in the industry that the weld joints formed by the welding motion in parallel direction produce greater strength than those by the transverse motion. For example, if a square box, formed by vibration welding the top and bottom halves, is tested for burst strength, the crack would start from the transversely welded joined side first. This paper attempts to evaluate such angular variation of weld joint strength with respect to the vibration welding direction, in the horizontal plane.

Another issue with vibration welding, particularly for air intake manifold application, is that the weld strength varies significantly from one location to another along the curved runner section area. The weld strength peaks at the sections where the clamp force vector is parallel to the weld face normal, and it keeps decreasing as clamp force vector deviates further from the weld face normal, until the angle between the two vectors make 90 degrees. Therefore it is common practice in the industry to limit this angle to +/- 70 degrees. However there is no study that shows relative joint strength of a vibration welded joints as a function of this weld angle in this vertical plane. This paper will make a first attempt to characterize such angular strength variation

### **EXPERIMENTAL PROCEDURE**

#### **MATERIAL**

The material used in this study is Carpon 8233(GHS BK102), a 33% glass reinforced Nylon 6 material from BASF Plastics. The material is currently in several air intake manifold applications. All tests have been made in dry as molded condition (DAM).

## STRENGTH EVALUATION OF WELD JOINTS. IN HORIZONTAL PLANE

### TEST SPECIMEN DESIGN

In order to determine the weld strength of a horizontal weld joint, a 0.125" (3 mm) thick clam shell pressure vessel has been designed, as shown in Figure 1. The test mold is shaped like a "Cereal Bowl", and it is equipped with an insert tool so different thickness weld beads can be molded in, so one mold can make both upper and lower shell of the test sample. For the present study the weld bead for the upper shell is 0.31" (6 mm) and the weld bead for the lower shell is designed with 0.16" (4 mm)

In order to eliminate the influence of trapped flash volume on the weld strength, we have eliminated flash trap walls. The part has a marker on the outside of the shell to indicate the direction of weld.

### VIBRATION WELDING

Injection molded Capron 8233 samples were vibration welded using three processing parameters as variables, clamp pressure, melt down and hold pressure. The levels of each parameter used in the experiment are listed below.

Clamp Pressure, psi: 80, 160, 220, 280 (600, 1200, 1600, 2150 lb clamp force is applied to net weld joint area of 7.44 square inch, for each pressure)

Melt Down, inches: 0.030, 0.045, 0.060, 0.075, 0.090

### BURST TESTING

The welded test samples have been connected to a burst test fixture, at room temperature, as shown in Figure 2. The sample was initially filled with room temperature water and then pressurized with nitrogen gas. Pressure was gradually increased at the rate of 116 psi per minute. And the burst pressure was recorded. Weld strength of each pressure vessel was calculated by the relationship between the applied pressure vs weld bead stress, established by an FEA analysis of this model. Figure 3 shows the stress distribution of the pressure vessel under 118 psi internal pressure.

## STRENGTH EVALUATION OF WELD JOINTS. IN VERTICAL PLANE

A 4" flat disc was machined from a 0.156" thick flat plate. Then using another plate, a 4" diameter half circle was machined off from one of the plate's edge. These two samples were then welded together along the circular mating line, using various melt down amount: 0.040", 0.060" and 0.080" (Val, what is the clamp pressure used?) Figure 4 show the schematic picture of the circular weld sample.

Then micro-tensile samples have been machined from this welded plate at various locations of the weld joint: 0, 30, 45, 60 and 75 degree angular positions. Local tensile strength was measured from these micro-tensile specimens and reported as angular strength variation in 'vertical plane'.

## **RESULTS AND DISCUSSION**

### WELD STRENGTH OF WELD JOINTS UNDER INTERNAL PRESSURE LOADING

The burst test result, shown in Figure 5 shows that the weld strength is strongly affected by the clamp force; smaller the clamp force, greater the weld strength. The influence of the melt down showed some optimal condition at 0.060", although the trend was not apparent at intermediate clamp pressure condition. However, the shape of the response surface was very similar to the one obtained an air intake manifold part.

Using the FEA model, strength values of the 'cereal bowl' weld joints have been calculated from the experimental burst pressure value. These strength values have been compared against the tensile strength of weld joints obtained from flat plaque samples, in Figure 6. It is shown that the weld joint strength of real weld joints can, in fact be improved as much as 70% through optimum welding condition; compared to only 10 to 15% improvement predicted by a standard weld joint test plaques.

## ANGULAR VARIATION OF WELD JOINT STRENGTH- HORIZONTAL PLANE

The welding specimens was placed in the welding fixture such that a small molded in marker on the specimen is aligned perpendicular to the welding head movement direction, as shown in Figure 7. During the burst tests, crack initiation location has been monitored, with respect to the raised marker location and recorded along with the burst pressure values. Failure initiation at location 1 or 3 indicate weaker joint strength along the parallel direction, failure along the location 2 or 4 indicate inferior weld strength in the transverse direction.

Of the 34 samples tested we have observed 31 samples started crack at location 3; only three samples had crack initiation at other locations. This indicate that the weld line strength is actually weaker in the parallel direction, rather than the transverse direction, as common sense dictates.

Figure 7 Top view of the 'cereal bowl', showing zero angle marker with respect to the welding motion direction.

This observation need to be tested further with direct measurement of local strength, such as bending test using a specimen taken from the local area.

## ANGULAR VARIATION OF WELD JOINT STRENGTH- VERTICAL PLANE

Figure 8 shows the local tensile strength values as a function of angular location in a circular weld joint. Zero weld angle corresponds to flat, horizontal and the weld planes get more vertical as the circular angle increases.

As shown in Figure 8, the weld strength remains almost constant up to 45 degrees, and it starts to drop off as the angle gets steeper. It is interesting to note that the strength drop gets less significant as the melt-down amount increases from 0.060" to 0.080". However, the results from the weld joint at 0.040" melt-down produced unpredictable results.

## **SUMMARY AND CONCLUSIONS**

Based on the experimental evaluation of a vibration welded 'cereal bowl' sample we make following conclusions:

- 1) The vibration welding strength can be improved by as much as 70%, through welding process optimization, compared to only 10% to 15% realizable through optimization of flat tensile bar samples
- 2) Most of the cracks in the cereal bowl samples started at the location where weld beads run parallel to the welding head movement, suggesting that the parallel direction weld may be weaker than the transverse direction of the welding. However, this observation need further proof through direct measurement of local strengths.

Based on the micro-tensile evaluation of a circular weld joint in a vertical plane, we make following conclusions:

- 3) Weld strength remains almost constant from zero to 45 degree of vertical weld angle. The weld strength start to drop off continuously, until it reaches 75 degree vertical angle.
- 4) At large angle region, increasing the melt-down to 0.080" helps reduce the strength drop off and maintain relatively constant strength throughout the whole curved weld line.
- 5) 0.040" melt-down produced somewhat erratic weld strength at high vertical angle region.

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## **REFERENCES**

1. V.Kagan, Siu-Ching Lui, G.R. Smith, J. Patry, "The Optimized Performance of the Linerar Vibration Welded Nylon 6 and Nylon 66 Butt Joints, 1996 SPE ANTEC, pp1266-1274
2. C. Lee, V. Kagan, N.Knowlden, K.W. Kim, H.D. Kim "Optimization of Vibration Welded Joint Strength for Plastics Air Intake Manifold", 1998 SAE Paper No.980730

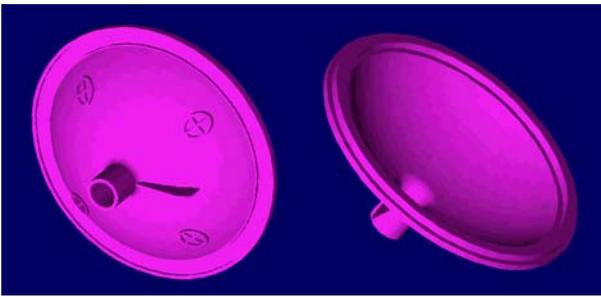


Figure 1: 'Cereal Bowl' Burst Test Sample Geometry



Figure 2: 'Cereal Bowl' sample, after the burst testing

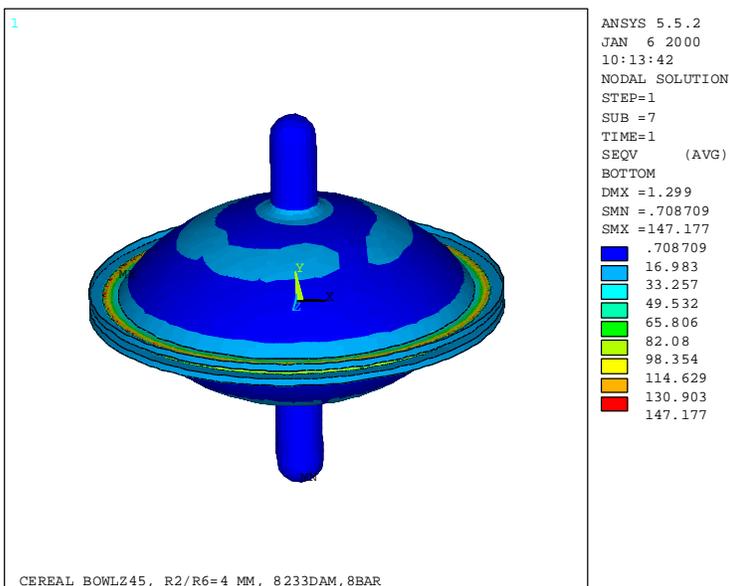


Figure 3: FEA model of the pressure vessel and the stress distribution under 118 psi internal pressure

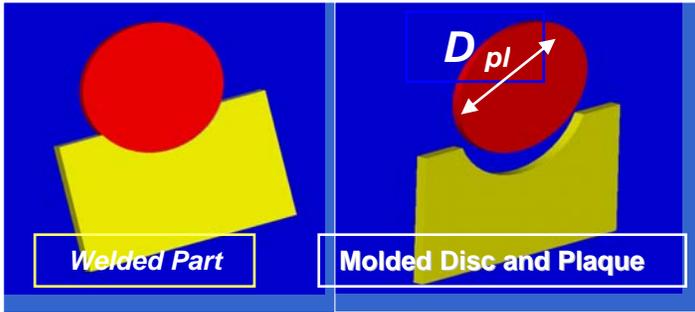


Figure 4. Circular weld joint test sample

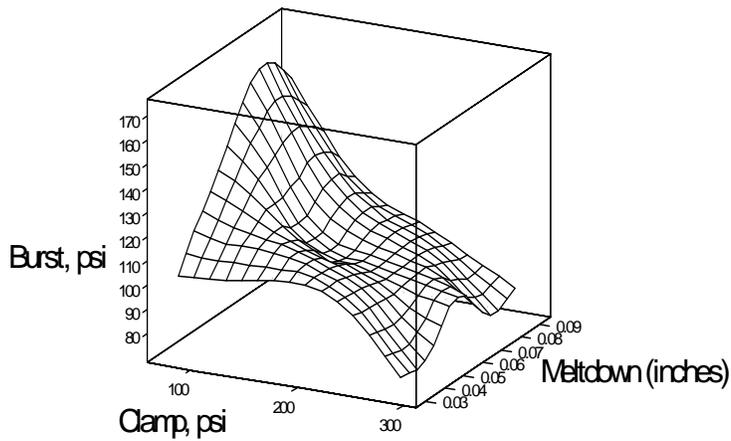


Figure 5. Burst pressure of 'cereal bowl' as a function of clamp pressure and melt-down.

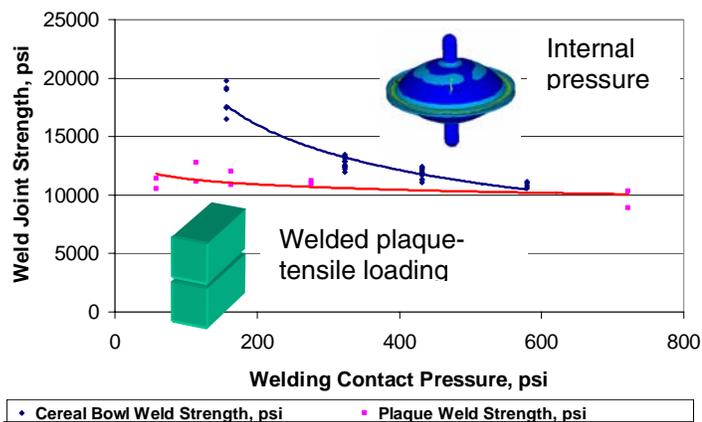


Figure 6. Tensile strength obtained from flat plaque weld joint and weld strength of a 'cereal bowl'

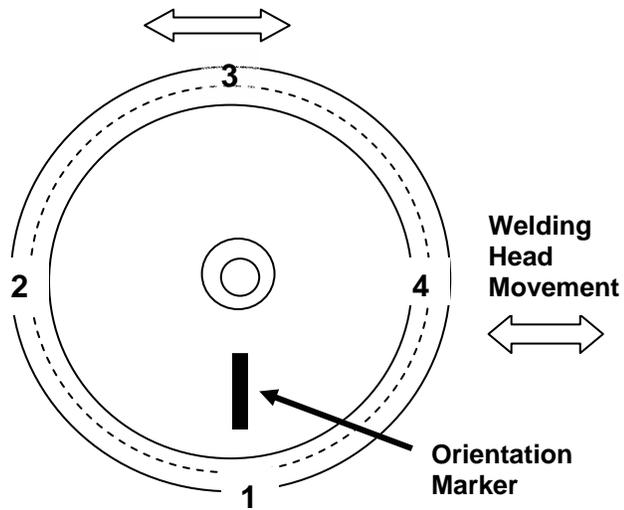


Figure 7 Top view of the 'cereal bowl' sample, showing zero angle marker with respect to the welding motion direction. Majority of failure started from location 3, a parallel direction welding location

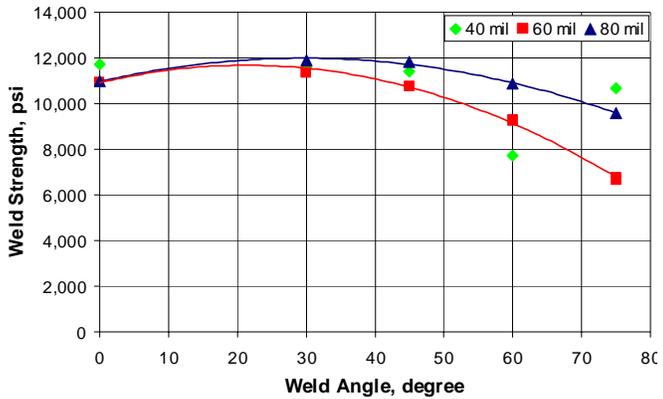


Figure 8 shows the local tensile strength values as a function of angular location in a circular weld joint.

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