Plastic
Processes, Components, and Technology

SAE INTERNATIONAL SP-1534

Plastic Processes, Components, and Technology

SP-1534

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Published by:
Society of Automotive Engineers, Inc.
400 Commonwealth Drive
Warrendale, PA 15096-0001
USA
Phone: (724) 776-4841
Fax: (724) 776-5760
March 2000

ISBN 0-7680-0584-1
SAE/SP-00/1534
Library of Congress Catalog Card Number: N98-42939

Printed in USA

PREFACE

This SAE Special Publication, Plastic Processes, Components, and Technology (SP-1534), is a collection of papers from the "Plastic Underhood Components" and "Advances in Plastic Components, Processes, and Technology" sessions of the SAE 2000 World Congress.

Special thanks to the organizers, chairpersons, and authors who made this Special Publication possible.

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2000-01-0040

General Guidelines for Improving Burst Pressure Strength of Welded Nylon Air Intake Manifolds

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ABSTRACT

Plastic air intake manifolds are successfully replacing aluminum air intake manifolds in most passenger cars and light trucks. Lower weight, performance and costs are the main reasons behind this trend. Of late, welded manifolds are becoming more popular than the lost core manifolds due to ease of manufacturing, lower costs, design flexibility and parts consolidation. The main disadvantage of welded manifolds is the reduced strength of the weld joint resulting from the fact that the glass fibers do not flow across the weld during the welding process. The Original Equipment Manufacturers (OEM's) specify a minimum burst pressure requirement for air intake manifolds and are continuing to seek higher burst pressure values. General design guidelines and welding processing conditions to improve the burst pressure strength of air intake manifolds are given in this paper.

The general shape of a manifold, particularly the plenum, plays an important role in the burst pressure strength of welded manifolds. The advantages and disadvantages of various shapes with respect to burst pressure strength are discussed in this paper. The effect of incorporating ribs and posts is also evaluated. The weld thickness and quality, which play a major role, are also discussed. Numerical simulations using the finite element method were conducted to come to these conclusions.

Also, discussed in this paper is how welding variables affect the burst pressure strength (a measure of weld strength of the plastic joint) for a particular weld joint design.

INTRODUCTION

In most passenger cars and trucks, aluminum air intake manifolds (AIM's) are being replaced by nylon AIM's. The main driving force is the lower weight and costs associated with it. Lost core manifolds have given way to welded manifolds because of the ease of manufacturing, design flexibility, parts consolidation and lower costs. The main disadvantage of the welded manifold is the strength of the weld joint. Since the glass fibers tend not to flow across the weld, the weld is not as strong as the rest of the material and it approaches properties of an unfilled nylon. Thus, the weld is generally the weakest part of the manifold. Material suppliers have done a great deal of work to improve their products such that when welded they have improved burst pressure strength. However, one area that is not frequently discussed is the role of the part design in improving burst pressures. By following good design practices, one can reduce the stress level in the weld joint, thereby increasing the burst pressure. General design guidelines and weld processing conditions to improve burst pressure strength of welded manifolds are discussed in this paper.

The Original Equipment Manufacturers (OEM's) have specific burst pressure requirements for AIM's. The motivation and purpose for the present study is derived from our experience in meeting these requirements. These standards generally specify a certain internal pressure the manifold should be able to withstand without failure. Various numerical simulations were carried out on a generic finite element model of a plenum to come up with the design recommendations. Experiments were also carried out to see the effect of welding conditions on the weld strength. Important conclusions drawn from these experiments are also given in this paper.

NUMERICAL SIMULATION

A baseline finite element model of a plenum using shell elements was considered for the initial analysis. It is in the form of a closed cylinder, as shown in Figure 1. The wall of the plenum was assumed to be 3 mm and the top and bottom weld width to be 4 and 6 mm, respectively. The flash traps were not included in the model for simplicity. A typical weld section is depicted in Figure 7. Material properties for glass reinforced nylon were assumed for the model. A finite element structural analysis using standard commercial software was carried out for evaluating various modifications. An internal pressure load of 100 psi (0.69 MPa) was considered for all iterations. In the baseline analysis (see Figure 2), the highest stress (97 MPa) is obtained in the weld in the end cap region which is relatively flat. This is the weakest section of the weld. The objective was to reduce the stress values in this region through various design modifications. The modifications considered for the plenum included change in shape, increased weld width, incorporation of ribs and posts and change in the offset of the weld section. All modifications were made with respect to the baseline model. The results of the iterations are summarized in Table I.

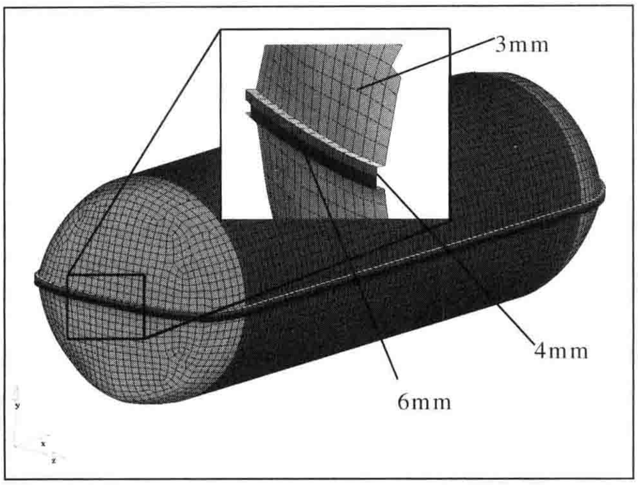

Figure 1. Finite Element Model of Welded Plenum

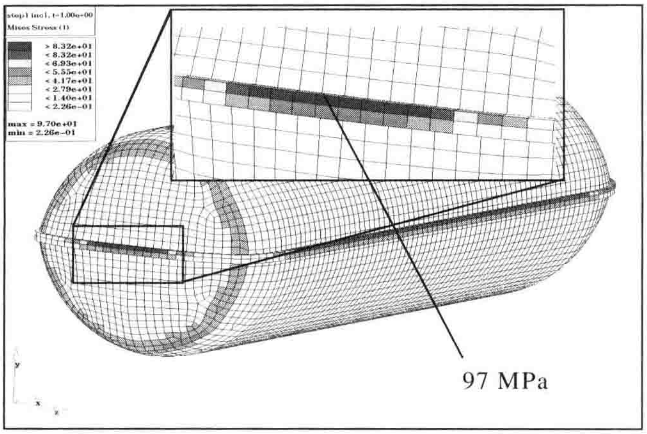

Figure 2. Stress Contour for Baseline Model

CHANGE OF SHAPE – The first modification involved introducing more curvature (dome shaped) in the end cap (see Figure 3). This tends to distribute the stresses more uniformly. There is almost a 45% drop in the peak stress value in the concerned weld region. A curved shape also helps to improve the vibration and acoustics characteristics of a manifold. Sometimes, packaging and internal volume constraints may prevent the use of a convex shape. Otherwise, it is a very effective tool for improving the weld strength.

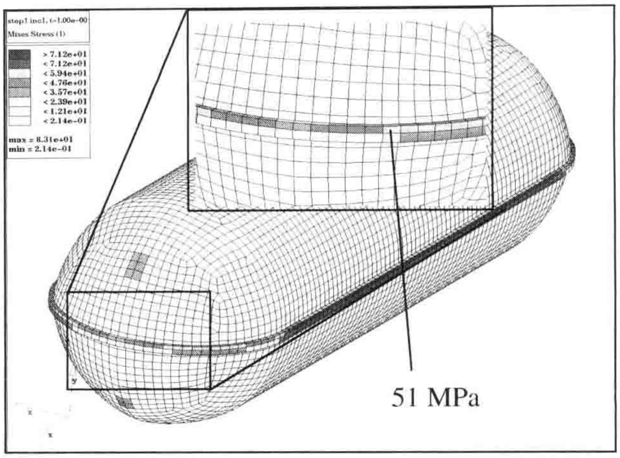

Figure 3. Stress Contour with Dome Shaped End

WIDER WELD SECTION – The width of the top and bottom weld beads were increased to 6 and 8 mm, respectively, in the end cap region. The results, which are depicted in Figure 4, show almost a 45% improvement in the stress values in the weld. The horizontal wall section shows a higher stress value but it is stronger than the weld joint. Increasing the width to some extent should not be too difficult in most cases. The energy required for welding may be an issue with wider welds.

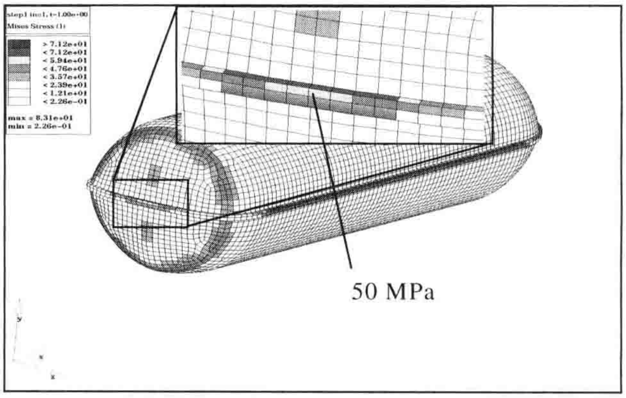

Figure 4. Stress Contour with Wider Weld Section

INCORPORATION OF RIBS – Ribs were incorporated on both sides of the flange as shown in Figure 5. The stresses for this iteration are also depicted in Figure 5. There is some reduction (about 10-15%) in the stress values compared to baseline results. The incorporation of ribs on the flange does not pose much of a problem as far as packaging and tooling constraints are concerned. The ribs also tend to increase the flange stiffness which reduces the flange deformation during the welding process, thereby increasing the weld quality. It also helps from a vibration and acoustics point of view.

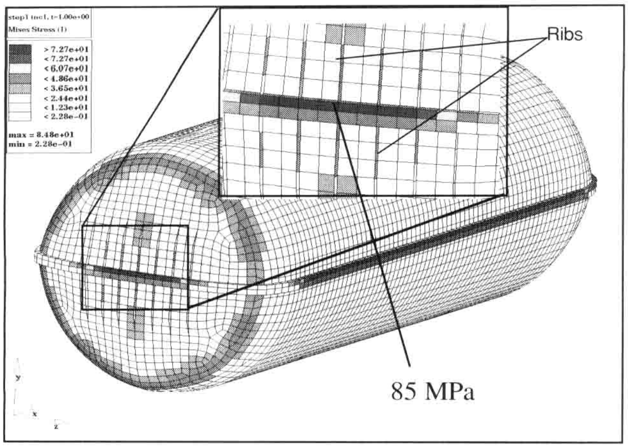

Figure 5. Stress Contour with Ribbed flange

INCORPORATION OF POSTS – In this iteration, the top and bottom halves of the plenum were tied (welded or bolted) together by three hollow posts, as shown in Figure 6. The stress values for this modification are also shown in Figure 6. The stresses show only an incremental reduction over the baseline values. However, the introduction of posts for improving weld strength depends to a large extent on the geometry of the plenum. They are an effective way of reducing weld stresses in many situations. The weld region nearest to a post has the greatest benefit in terms of stress reduction. The advantage of introducing posts can easily be determined for a specific design by numerical simulation. They seem to work well for plenums which are flatter. The posts also tend to increase the overall stiffness of a manifold. The posts also reduce the internal plenum volume which may affect the engine output.

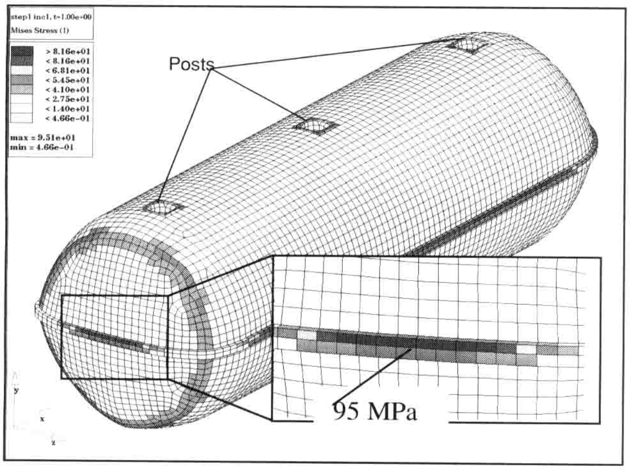

Figure 6. Stress Contour with Posts Tying Top and Bottom

CHANGE IN OFFSET OF WELD SECTION – In standard weld designs, as shown in Figure 7, the weld beads are offset from the main wall of the manifold. This imparts a bending load on the weld resulting in high stresses. In the modified design shown in Figure 8, the weld beads are aligned with the wall of the manifold. Removing the offset reduces the bending load on the weld. The stress contour plot with this modification is shown in Figure 9. The stresses are reduced in the concerned weld region by up to 60%. The main drawback with this modification is the requirement of special fixture due to the step in the weld section (see Figure 8) which prevents easy withdrawal of the fixture. However, it is a very effective way to reduce the stresses in the weld. This design modification should be an option if all other efforts to improve the weld strength are futile.

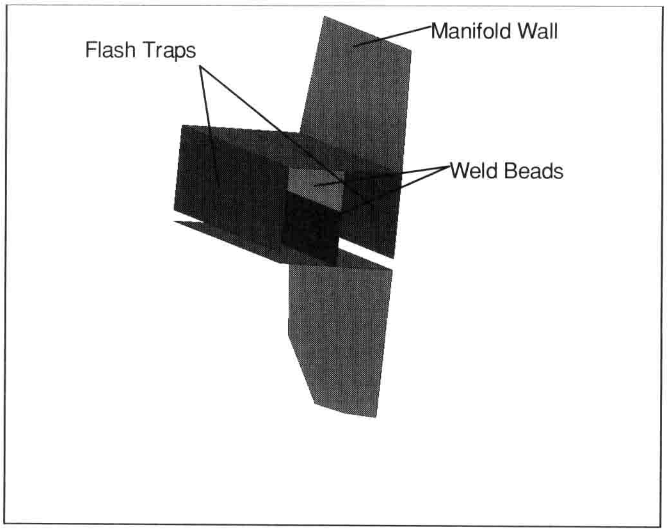

Figure 7. Baseline Weld Section

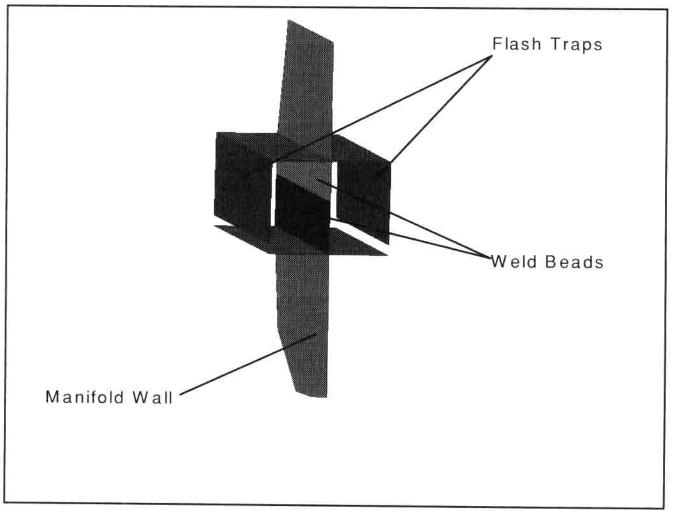

Figure 8. Modified Weld Section with No Offset

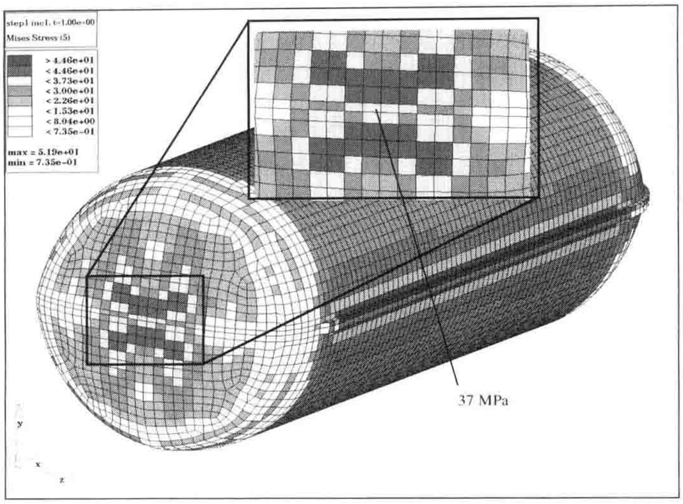

Figure 9. Stress Contour for Modified Weld Section (No Offset)

The results of the various iterations are summarized in Table I. Even though these values are specific to this design, it gives a good indication of the effect of each modification. A numerical simulation is the best way to determine the benefit of any of these modifications for any specific design.

Table 1. Design Modifications

	Design Modification	Maximum Weld Stress (End Cap Region), MPa
1	Baseline	97
2	Dome Shaped End Cap	51
3	Weld Thickness Increase by 2mm	50
4	Presence of Ribs	85
5	Presence of Posts	95
6	Reduction in Weld Offset	37

An example of a progressively improved design is depicted in Figures 10-13 which shows part of a flange with a weld bead circumventing a bolt hole. The design is improved by increasing weld bead width in the sharp curvature (see Figure 11) and then by reducing the concavity in the curvature, as shown in Figure 12. Figure 13 shows a secondary weld in addition to a primary weld. This helps to increase the weld contact area similar to the effect of increasing the width. Since the secondary weld is detached from the primary weld, any failure in this weld will not propagate to the primary weld, thereby preventing any leakage.

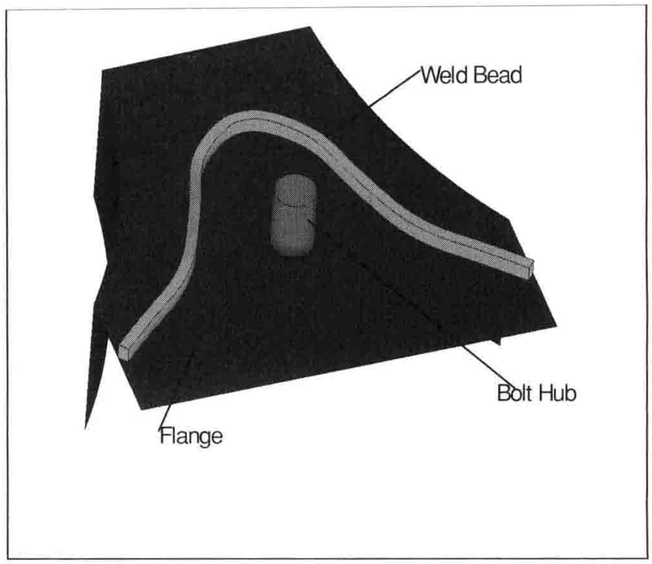

Figure 10. Flange Section with Weld Bead

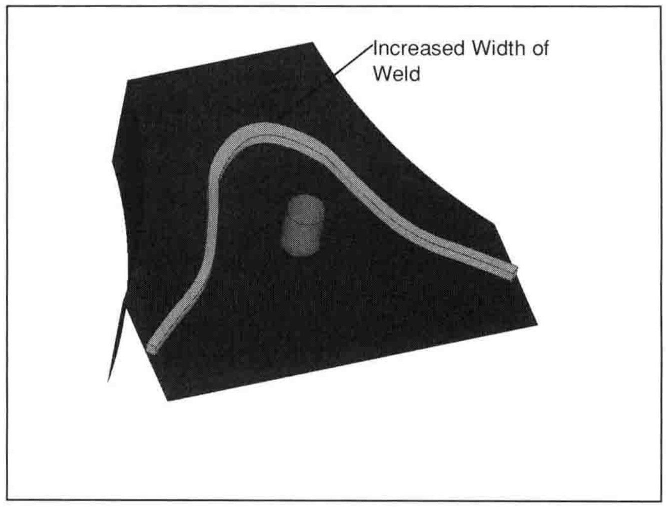

Figure 11. Modified Weld Bead (Increased Width)

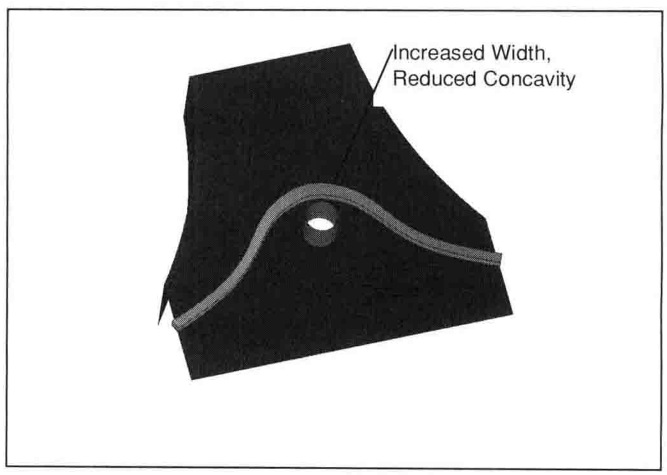

Figure 12. Modified Weld (Reduced Concavity)

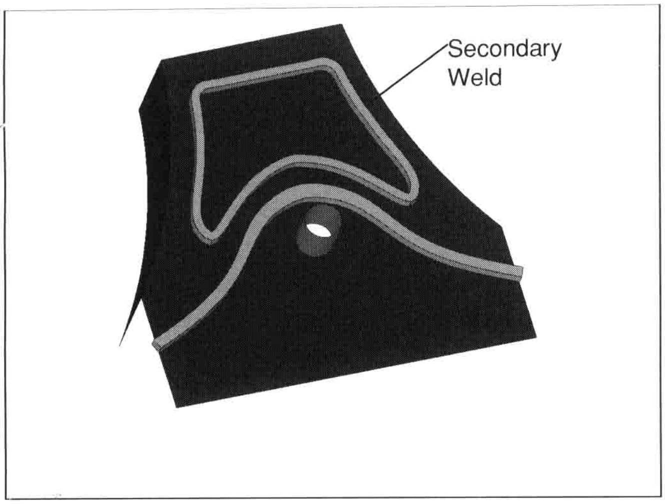

Figure 13. Modified Weld (Presence of Secondary Weld)

WELDING CONDITIONS

Apart from the design recommendations listed above, one should consider the impact of welding conditions on the burst pressure strength. A study illustrating the effect of welding conditions on a spherical shape is discussed below. It is shown that changes in welding conditions can effect burst pressure strength significantly.

Two spherical halves, as shown in Figure 14, were welded together under various welding conditions and then tested for burst pressure strength. Some of the welding conditions considered were friction pressure, welding pressure, cooling pressure and melt distance. The burst pressure strength for the sphere is given in Table II for different welding conditions. It can be seen from the results in Table II that by varying vibration welding conditions one can improve the burst pressure strength. Hence, it very important to optimize the processing conditions for a specific weld design to get maximum weld strength. Details of the investigation of welding conditions and materials will be subject of another paper.

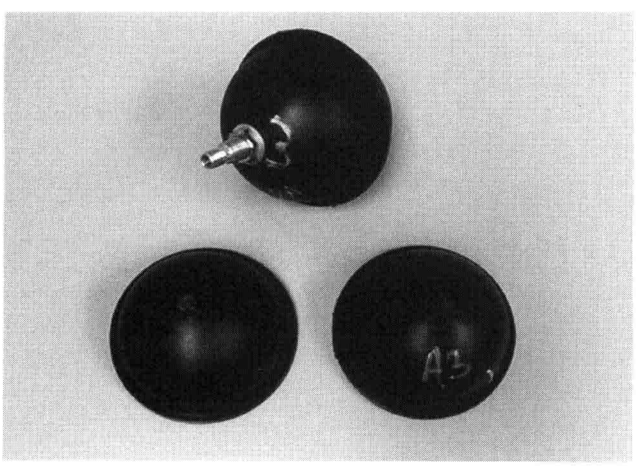

Figure 14. Spherical Halves Used in Testing

Table 2. Vibration Welding Conditions

Condition	1	2	3	4	5
Friction Pressure, (bar)	30	30	30	40	30
Welding Pressure, (bar)	20	20	20	20	20
Cooling Pressure, (bar)	15	15	15	15	20
Melt Distance, (mm)	3.5	2.7	2.5	2.7	3.5
Burst Pressure Strength, (psi)	355	268	247	259	331

CONCLUSIONS

General guidelines to improve the burst pressure strength of welded manifolds are discussed in this paper. The following summarizes some of the key points of this study.

- A convex curvature or reduced concavity for the weld bead greatly improves the weld strength.
- Increased weld bead width and/or the use of secondary welds improves the strength of the local weld region.
- Incorporation of ribs in the flange of the weld bead results in a small increase in the weld strength.
- Incorporation of posts in the center of plenum helps the overall weld strength but the improvement depends on a specific design.
- A reduction in the offset of the weld bead from the wall (Figures 7, 8) reduces the stresses in the weld significantly.
- The most important point to remember is the need to optimize vibration welding parameters for any specific weld design to obtain maximum weld strength.

ACKNOWLEDGEMENTS

The spherical parts used in the testing were made with tools provided by Flambeau Plastics, Baraboo, WI 53913.

2000-01-0041

Development of Plastic Intake Manifold by DRI Process

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ABSTRACT

We have succeeded in applying a new injection molding method, die rotary injection (DRI), for plastic intake manifold production. Polyamide 6 and polyamide 66 are the optimum materials with consideration of the mechanical properties and the durability against heat and chemicals. Though the conventional plastic manifolds are mostly made by polyamide 66, polyamide 6 showed preferable characteristics for the injection welding technology that we have developed.

Measurement of welding strength and observation of fracture surface were carried out by using specimens that were cut from the real products. High welding strength without delamination of the welding surface was confirmed in the molding condition up to high cylinder temperature and high injection rate.

1. INTRODUCTION

Because plastic automobile parts contribute to weight reduction and low fuel consumption, interior and exterior parts, such as the bumper, instrument panel and door trim, have been converted from metallic materials to plastic materials.[1),2)] However, the functional parts have not been replaced by plastic materials due reliability issues. In recent year, plastic intake manifolds have been developed because of many advantages[3)-6)]:

1. Weight reduction
2. Cost reduction by elimination of machining process
3. Achievement of high performance of engine due to high surface smoothness and increasing of heat isolation

To achieve greater cost reduction, a new molding process, die rotary injection (DRI) has been developed [7)], and we have succeeded applying to intake manifolds.

Fig. 1 shows the schematic representation of the DRI process. In this process, two halves, the upper and lower, are molded. The mold is opened while retaining the molded part halves in the mold. Next, one die is rotated before the mold is closed. Finally, resin is injected in the mold to weld the halves together. At the same time, two new halves are also molded in the other part of the mold.

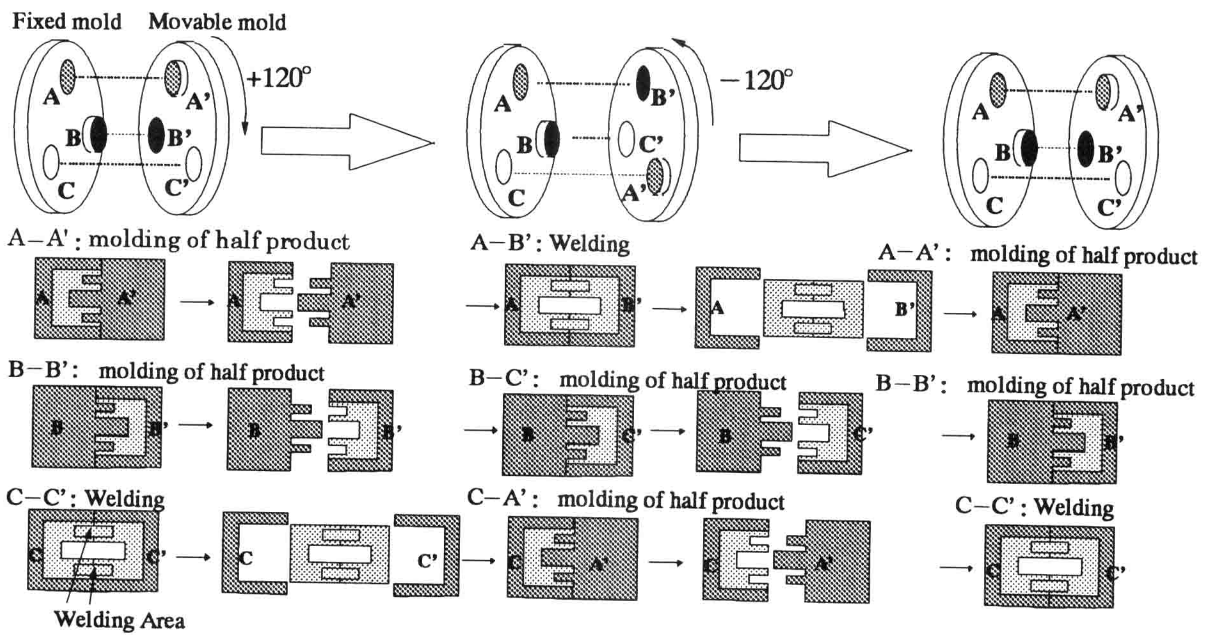


Figure 1. Schematic representation of DRI process

In DRI the process, one completed product can be molded in one injection cycle just in the conventional injection molding process. The most important point of this process is to ensure reliability of welding because the welding condition affect the morphology and mechanical properties of welding. In this study, the welding mechanism of the DRI process was clarified. Material properties and molding conditions were also studied to achieve high welding reliability.

2. EXPERIMENTAL

2.1 INVESTIGATION OF WELDING MECHANISM

2.1.1 Materials – In this study, polyamide 6 and polyamide 66 were used with consideration of mechanical properties, heat and chemical resistance for intake manifold.

2.1.2 Molding method – In this paper, we defined the strength after welding as "welding strength". Welding strength was measured by the original tensile specimen to judge the optimum welding conditions. Fig.2 shows the specimen geometry. This specimen modeled the material flow of DRI process. First, half of the specimen was molded (Primary molding in the white area). Second, the half of the specimen was inserted in the mold of dumbbell shaped specimen (ASTM-1), and resin was injected in the gap of the mold to weld (Secondary molding). Then the specimen of measuring welding strength was completed. To observe the welded surface, natural and black colored materials were used for primary and secondary molding respectively.

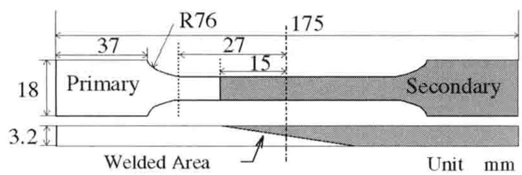


Figure 2. Geometry of specimen

Table 1 shows molding conditions. Three levels of the cylinder temperature, the injection rate and the mold temperature were applied, and specimens were molded by following L_9 orthogonal array. The primary molding was molded by the medium level that is the standard conditions of each material.

Table 1. Molding conditions

	Mold Temp. (℃)			Cylinder Temp. (℃)			Injection Rate (cm^3/s)		
	1	2	3	1	2	3	1	2	3
PA6	65	75	85	230	245	260	50	100	150
PA66	65	75	85	265	280	295	50	100	150

2.1.3 Tensile test – Tensile test was carried out to measure the welding strength under 20mm/min of testing speed.

2.1.4 TEM observation – To clarify the welding mechanism, the welding surface was observed by transition electron microscope (TEM). Fig.3 shows the geometry of observed sample in the tensile specimen. Thickness of the sample was 1000 and was colored by OsO_4 before it was observed. The specimen was observed at 200kV of acceleration voltage and at 150,000X magnification.

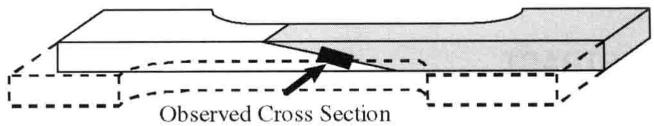


Figure 3. TEM sample

2.2 EXAMINATION OF THE PRODUCTS

2.2.1 The aim of the test – In the previous section, the optimum material for DRI process was selected by applying the welding mechanism. To achieve high reliability of the products, it is necessary to obtain high welding strength in all through the welding area constantly. Therefore, the products were molded by various molding conditions, and the strength of the specimens that were cut from the products, were measured to find the best molding conditions.

2.2.2 Molding method – Molding conditions of the products are shown in Fig. 4. The upper and lower limit of cylinder temperature and injection rate were selected and combined together.

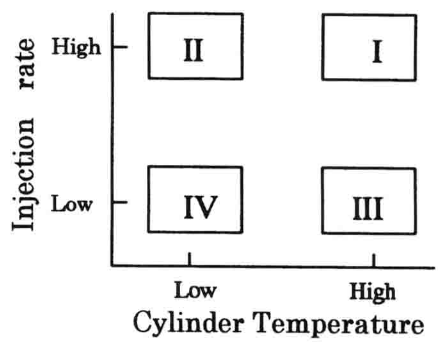
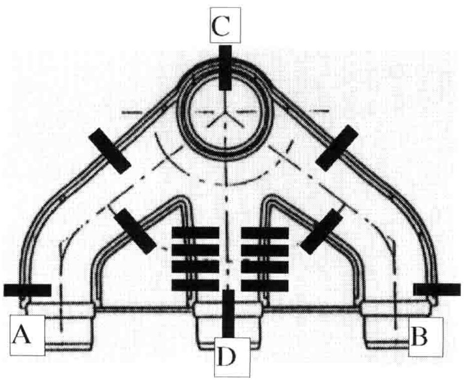


Figure 4. Molding conditions of the products

The important point of selecting cylinder temperature is described below. The upper limit of cylinder temperature is set up in consideration of heat degradation and the lower limit is set up to the temperature that the resin flow to the end of the mold before it is cooled and solidify to get high welding strength. The important point of selecting injection rate is described below. The upper limit is the temperature that the resin does not stick from the products. Resin sticking cause not only the spoiling of the appearance but also decreased the engine performance by increasing the flow resistance of the air.

The lower point is set up the rate that the resin is able to flow to the end of the mold before it cooled and solidify as same as cylinder temperature.

2.2..3 Tensile test – The cutting point of the specimens from the products is shown in Fig. 5. The welding resin is injected from A and B, and is joined in C and D. The flow length of the resin from A or B to C is 170mm, and from A or B to D is 200mm. The specimens were cut at the middle point of A-C, A-D, B-C and B-D. Moreover, several points on A-D and B-D were picked up with consideration of delamination of the welding surface because the resin flow to the end of the mold more difficult than other sides. The geometry of the specimen is shown in Fig. 6. Welding strength was measured by tensile test and the fracture surface was observed.



A, B : Gate of welding resin
C,D : Jointing point of welding resin
▬ : Position of test piece

Figure 5. Position of specimens

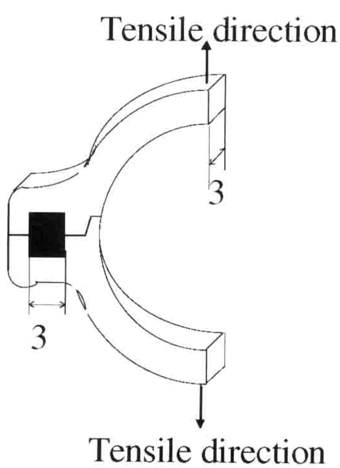


Figure 6. Geometry of specimen

3. RESULTS AND DISCUSSION

3.1 INVESTIGATION OF WELDING MECHANISM – Table 2-1 and 2-2 shows the results of welding strength of PA6 and PA66 respectively. In these tables, "Good" means the fracture without delamination of the welding surface as shown in Fig. 7(a), and "No Good" means the fracture with delamination of welding surface as shown in Fig. 7(b). PA6 has high welding strength without delamination whereas PA66 showed delamination under most of molding conditions. Even when PA66 showed no delamination, retention of strength was lower than that of PA6. Therefore, PA6 is a more suitable material than PA66 for the DRI process.

Table 2-1. Result of tensile test (PA6)

No	Mold Temp. (℃)	Cylinder Temp. (℃)	Injection Rate (cm^3/s)	Welding Strength (MPa)	Retention (%)	Fracture Mode
1	65	230	50	22.0	48.9	No Good
2	65	245	100	45.6	101.3	Good
3	65	260	150	50.0	111.1	Good
4	75	230	100	41.0	91.1	Good
5	75	245	150	46.3	102.9	Good
6	75	260	50	48.0	106.7	Good
7	85	230	150	44.0	97.8	Good
8	85	245	50	40.0	88.9	Good
9	85	260	100	48.0	106.7	Good

Good : No Delamination, No Good : Delamination
Retention (%) = Welding Strength ／Original Strength ×100

Table 2-2. Result of tensile test (PA66)

No	Mold Temp. (℃)	Cylinder Temp. (℃)	Injection Rate (cm^3/s)	Welding Strength (MPa)	Retention (%)	Fracture Mode
1	65	265	50	37.3	53.3	No Good
2	65	280	100	61.5	87.9	Good
3	65	295	150	57.2	81.7	Good
4	75	265	100	48.0	68.6	No Good
5	75	280	150	59.6	85.1	Good
6	75	295	50	48.2	68.9	No Good
7	85	265	150	50.0	71.4	No Good
8	85	280	50	45.1	64.4	No Good
9	85	295	100	56.2	80.3	Good

Good : No Delamination, No Good : Delamination
Retention (%) = Welding Strength ／Original Strength ×100

To clarify the difference between fracture modes of the specimen, the welding surface was observed by TEM. Fig. 8 shows the TEM graphs of the welding surface of PA6. In these micrographs, indicates the interface between the primary and the secondary resins. In the case of fracture without delamination, randomly oriented lamella was observed and the interface of welding was not observed clearly. In the case of fracture with delamination, the welding interface was observed clearly, and lamella growth from the interface to both the primary and the secondary resins was observed.

Summarizing these observation results, the welding mechanism was concluded as follows. In the case of specimen having high strength, the surface of the primary resin was melted by the secondary resin and mixed together before the resins solidified with crystallization. Therefore, we considered the necessary conditions for high welding strength as follows.

1. Material should be molded at high temperature and high injection rate.
2. Melting latent heat of the material should be lower than crystallization latent heat.

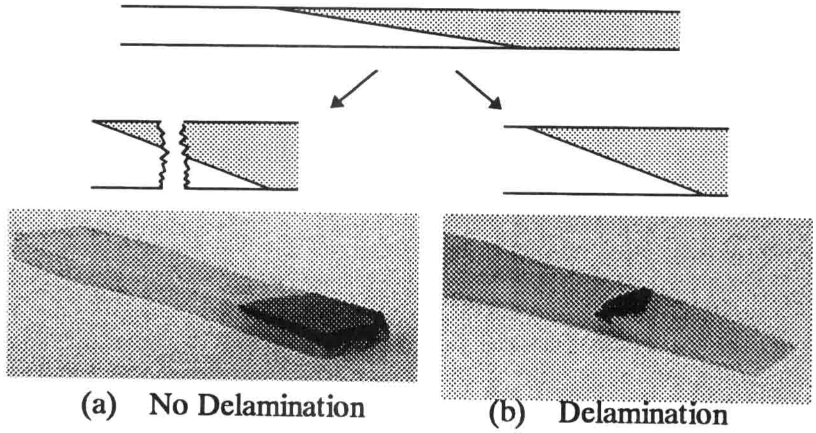


Figure 7. Photograph of fracture mode after tensile test

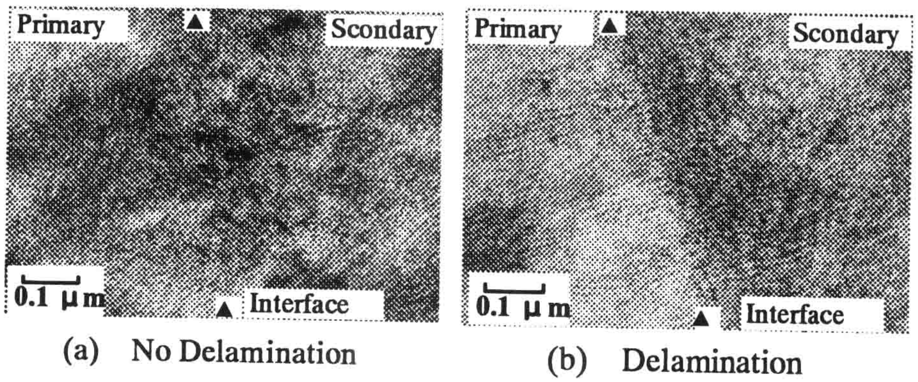


Figure 8. TEM graphs of welding surface

To verify this estimation, the welding strength data were analyzed. Fig. 9-1 and 9-2 shows diagrams of factorial effect in PA6 and PA66 respectively. Welding strength was greatly affected by cylinder temperature and injection rate. High welding strength was achieved by high cylinder temperature and high injection rate. From this result, the optimum range of welding conditions for high welding strength was examined. Fig. 10 shows the results of examination of the optimum welding condition of PA6 and PA66 respectively. PA6 was able to be welded in standard conditions whereas PA66 was able to be welded in limited injection conditions of high cylinder temperature and high injection rate. Therefore, it is considered that PA6 is the more optimum material than PA66 for DRI process.

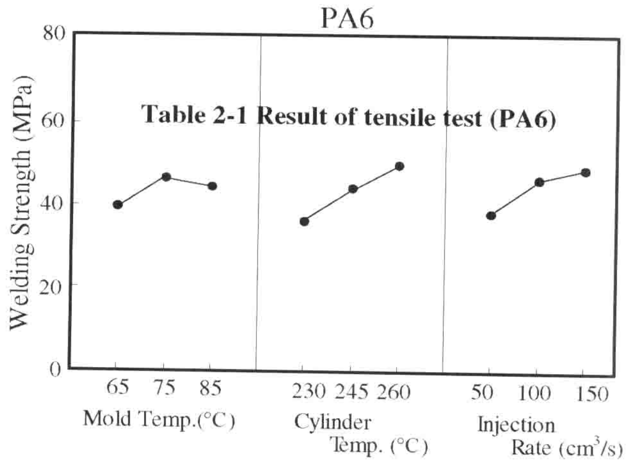


Figure 9-1. Effect of factors on welding strength (PA6)

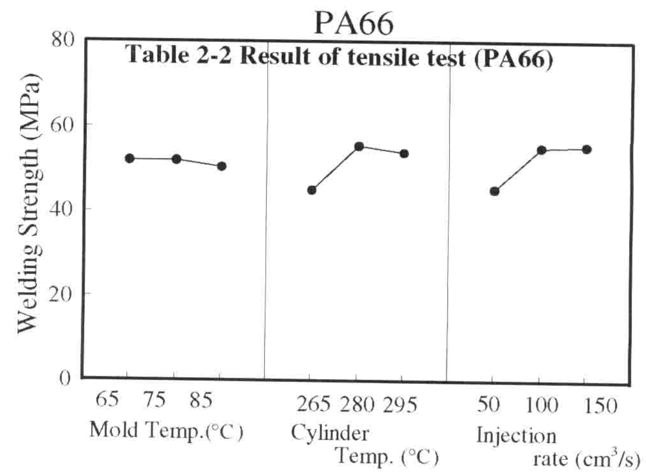


Figure 9-2. Effect of factors on welding strength (PA66)

The difference of injection condition range for high welding strength between PA6 and PA66 was explained by thermal properties of the materials. Fig. 11 shows latent heat of melting and crystallization of PA6 and PA66. Because melting latent heat of PA6 is lower than crystallization latent heat, the surface of the primary resin was melted by crystallization heat of the secondary resin, and high welding strength was achieved. On the other hand, PA66 was not welded at the temperature of the standard molding condition because melting latent heat is not lower than crystallization latent heat.

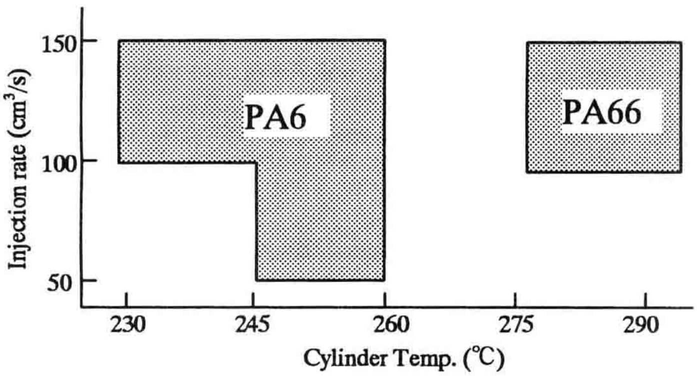


Figure 10. Molding condition range for high welding strength

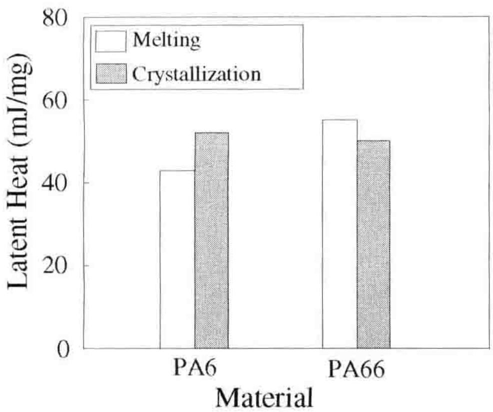


Figure 11. Latent heat of PA6 and PA66

3.2 EXAMINATION OF THE PRODUCTS – In the previous section, PA6 showed better characteristics for intake manifold production by DRI process. With consideration of strength and heat resistance for intake manifold, glass fiber reinforced PA6 was used for examination of the products.

Fig.12 to 15 show the results of tensile test. In condition I, welding strength gradually decreased with increasing flow length of welding the resin, but delamination did not occur at all position. Therefore, products have high welding reliability in condition I. At position D in condition I, the welding strength is lower than that at the other positions because the welding resin stopped and solidified. On the other hand, at position C, welding strength is not lower than that of position D. At position C, the extra cavity which is used to ensure that resin has filled the mold, is injected and the welding resin did not stop flowing until the extra cavity was filled. In other conditions, delamination was observed at several points on A or B to D because the welding resin lost heat during flow and it was not able to melt the primary resin. Therefore, low cylinder temperature or injection rate prevent the high welding strength the same as the results of the specimen.

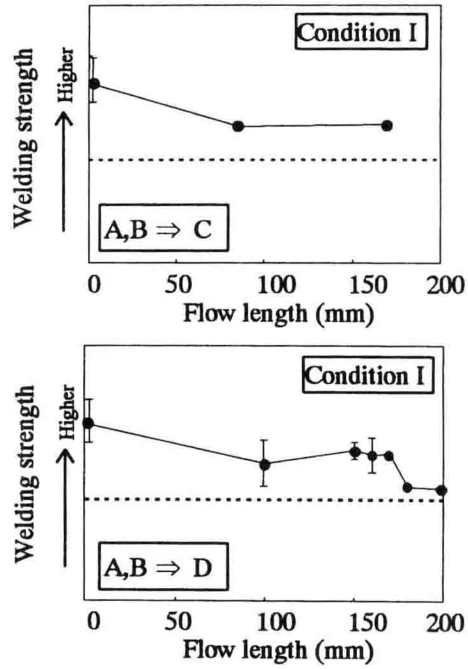


Figure12. Result of tensile test (Condition I)

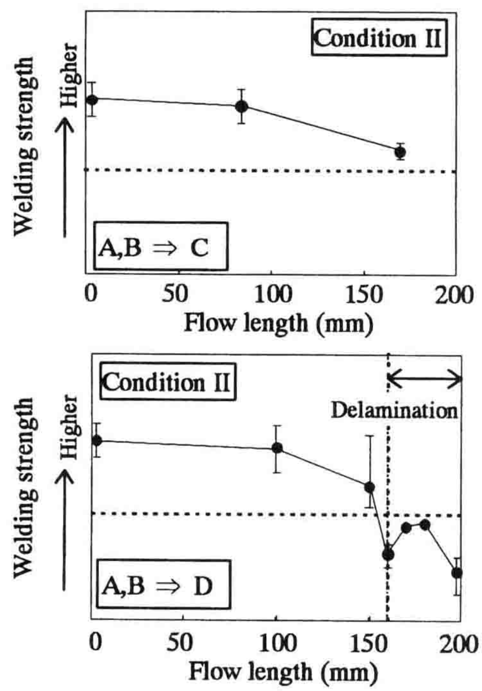


Figure 13. Result of tensile test (Condition II)