

# Effect of Securing Processes on Precision Assembly

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**Abstract** Assembly precision is important since it affects the product quality and production yield. One of the key steps in the assembly process is the fastening process. However, little research has been conducted in this area in terms of the effect of the securing process on the assembly accuracy. One of the difficulties to carry out the research in this area is the lack of proper instrument with high enough resolution to perform the study. Using an inhouse developed ultra-high resolution multi-dimensional position monitoring system, the effect of screw-fastening process and glue-bonding process on the final assembly precision in a controlled environment has been studied.

In our study of the screw-fastening process, the effects of different parameters such as number of screws, applying torques, holding force, external datum pins and washer have been investigated. Our analysis shows that these parameters would interact with each other in the contribution to the lateral and rotational displacement in the screw-fastening process. Number of screws and washer are the most significant factors for the translation displacement induced by the screwing process. As for the rotational displacement, the presence of the external pins, and the joint effect of holding force and number of screws are the more important factors. Our study shows that proper design and operating condition of the screwing process have a very significant effect on the level of displacement introduced by the screw fastening process. An order of magnitude difference (range from about a  $\mu\text{m}$  to over  $10\mu\text{m}$ ) in the assembly accuracy may result using different screw-fastening conditions.

In the glue-bonding process, the effect of different types of glues, and different type of glue-bonding configuration have been studied. For the side joint where glue is applied on the sides of the work piece, there is significant difference in performance when glue is applied on all sides versus just applied only on one side. UV glue and AAA bond work better in terms of accuracy than the epoxy. There is again close to an order of magnitude difference in performance of between the best glue-bonding application method and the worst application glue-bonding method. In the lap joint configuration where glue is applied to the backside of the parts, the displacement is mainly due to shrinkage of glue, and the shrinkage depends on glue thickness and glue shrinkage rate.

As a whole, the glue-bonding process can provide an order of magnitude better accuracy than the screwing process. The best glue-bonding process we have observed would only cause about  $0.1\mu\text{m}$  of displacement of the parts. In other words, our study shows that there are a two order of magnitude of difference in accuracy between an optimized and a non-optimized fastening process.

**Key Word:** Precision Assembly System, Fastening Process, Screw-fastening Process, Glue-fastening Process, Ultra-Precision Multi-dimensional Position Monitoring System

## 1. INTRODUCTION

Industry assembly is very important in production. As the final step in the manufacturing process, it directly influences the product quality and life cycle. Assembly is finished by a serial of assembly activities, such as alignment, jointing, insertion, fastening and bonding, that have the workpieces assembled together. Therefore, how good the assembly task is performed in assembly process is one of the important factors that will greatly affect the assembly quality.

In the assembly process, there are two basic categories of assembly task involved: parts mating and parts joining. In parts mating, two or more parts are brought into contact or aligned with each other. After parts are mated, fastening is applied to hold them together. A great deal of research efforts has been done in the past to deal with the problem of assembly inaccuracy in parts mating [1-3]. Although these progress, little research has been done in parts joining or fastening.

For assembly with bonding, it appears that relatively little systematic research and study has been done in this area. In industry, the level of precision achievable by bonding assembly is not well understood. This research tries to answer following questions; 1. What level of assembly accuracy will be achieved with glues at different joint conditions. 2. What factors will strongly affect the accuracy of assembly process by glues and how to prevent it. 3. What is the best way to reduce the effects of these factors to improve the level of precision.

There are many factors that may affect the precision of the bonding process. In the course of this investigation, the effects of whether the glue permeates into gap or not was found to have a strong effect than the other factors for side joint. For example, the AA glue exhibits a better accuracy than epoxy although the volume shrinkage of AA glue is much larger than that of epoxy.

Among all the factors that affect the precision of the assembly with bonding, how the workpiece is bonded is a factor in a class of its own deserving special attention. In this respect, a systematic study of the effect of joint conditions on the assembly precision has been conducted. Specially, it is aim of this study to understand the ultimate level of the performance of a well-performing assembly with bonding.

## 2. EXPERIMENT PROCEDURE

### 2.1 Experiment of screw-fastening process

Two workpieces with aluminum had been milled for the study. One was  $100 \times 130 \times 6.35 \text{mm}^3$  for the top piece and the other was  $98 \times 128 \times 12.7 \text{mm}^3$  for the bottom piece. A multi-dimensional high-resolution optical monitoring system [4] will be used to measure the displacement of the workpiece during the screw-fastening process. In our experiment, effects of several factors such as torque, washer, holding force, number of screws and mechanical constraint on the displacement of the piece during the screw-fastening process are to be studied. The impacts of these factors were also investigated via factorial experiments that can exam several factorial effects simultaneously.

### 2.2 Experiment of glue-bonding process

#### 2.2.1 Glue selection and characterization

Three kinds of commercially available glues with room temperature curing are chosen as bonding materials in our tests; 1. U-V glue (UV 82025, Electro-lite Corp.); 2. A-A glue (Aron Alpha, Toagosei co., Ltd); 3. Epoxy (Epoxy 5 minutes, Bostik, Australia Pty Ltd).

Two approaches are used to measure the volume shrinkage of the glues; i). To measure the shrinkage of the glues in a long glass tube. ii) To measure the shrinkage of a block of the glue in  $z$  direction. The volume shrinkage for UV and epoxy will be taken as the average of the values obtained by two ways. Table 1 shows the measured volume shrinkage by our approach.

**Table 1. The measured volume shrinkage of glues**

UV glue	AA glue	Epoxy
$k_{uv} = -7.69\%$	$k_{AA} = -60.38\%$	$k_{EP} = -3.28\%$

#### 2.2.2 Experiment setup for glue-bonding process

Two types of glue-bonding configuration were studied; i) side joint; ii) lap joint. Two kinds of work pieces of aluminum had been milled for side joint. One was  $46 \times 46 \times 20 \text{mm}^3$  for the top piece (piece1) and the other was  $110 \times 70 \times 12 \text{mm}^3$  for the bottom piece (piece2). For lap joint, the sizes were  $40 \times 40 \times 20 \text{mm}^3$  for piece1 and  $50 \times 50 \times 20 \text{mm}^3$  for piece2, respectively. Two experiment setups were designed for different joint conditions.

##### 1. Setup for measurement of displacement components in $xy$ plane for side joint

##### 2. Setup for measurement of displacement components in $z$ direction for lap joint

A developed multi-dimensional ultra-high resolution positioning monitoring system [5] is used to measure the displacement of the workpiece.

### 3. EXPERIMENT RESULT

For screwing process, the main effect plot in Fig. 1(a) suggests that number of screws and washer are the most significant factors for the translation inaccuracy induced by the screwing process. As for the rotational displacement, Fig. 1(b) indicates that the most important factors are the pins.

The results of glue bonding process for side joint show that, i) for all side joint conditions and glues used in test, the displacements are sub-micron. The four sides joint shows the best assembly accuracy and the one side joint condition exhibits a largest displacement among five conditions. ii) it is interesting that, for all conditions, the displacements for epoxy which exhibits a smallest volume shrinkage (-3.28%) among three kinds of glues are larger than that for UV and AA while the joints with AA glue show the displacement in almost same scale as that with UV glue although AA glue exhibits a significant volume shrinkage (-60.38%) among three glues (Fig. 1(c)).

For lap joint with nearly parallel gap, it can be seen that the displacement  $u_z$  for all gaps is in scale of microns and increases with an increase of the gap (Fig. 1(d)).

For lap joint with an inclined and a constant average gap, the results shown that, i) the average displacement  $u_z$  shows only about 5.4% different when the initial inclined angle varieties from  $\beta_x = 0$  to  $\beta_x = 7.5 \times 10^{-3} \text{ Rad}$ . For the applications with small inclined angle, we may regard that the average displacement  $u_z$  is independent on the initial inclined angle; ii) the magnitude of the rotation angle of the piece1 increases with an increase of the initial inclined angle as shown in Fig. 1(e).

### 4. CONCLUSION

1. The experiment results shown that number of screws, datum pins, washer and holding force are the important factors that affect assembly accuracy. That the order of magnitude difference in the assembly accuracy may result using difference screw-fastening conditions is also observed.
2. For all side joint conditions of bonding process, the displacements are sub-micron. The four sides joint shows the best assembly accuracy. The one side joint condition exhibits a largest displacement among five conditions. The results suggest that how the two pieces are jointed by glue is a major affecting factor of MAS precision.
3. For all side joint conditions, the displacements for epoxy that exhibits a smallest shrinkage among three kinds of glues are larger than that for UV and AA. The joints with AA glue show the displacement in almost same scale as that with UV glue while AA glue exhibits a much large shrinkage than that of epoxy.
4. For lap joint, the displacement  $u_z$  is close to proportional to the magnitude of the initial gap. The rotation angle is close to linear dependent on the initial inclined angle.

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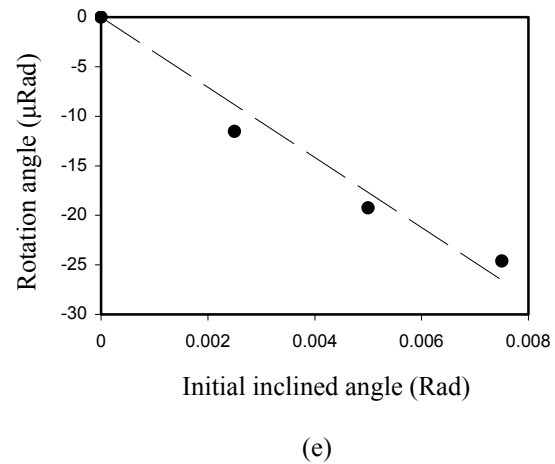
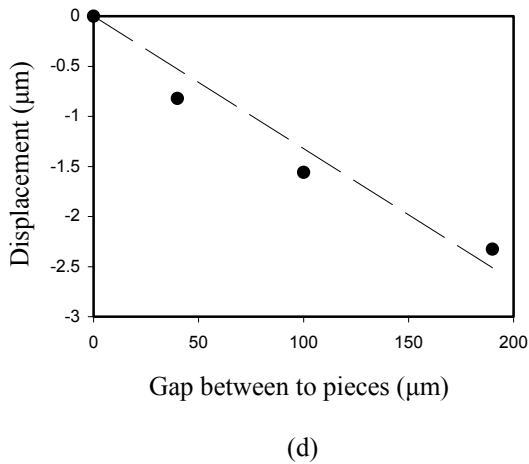
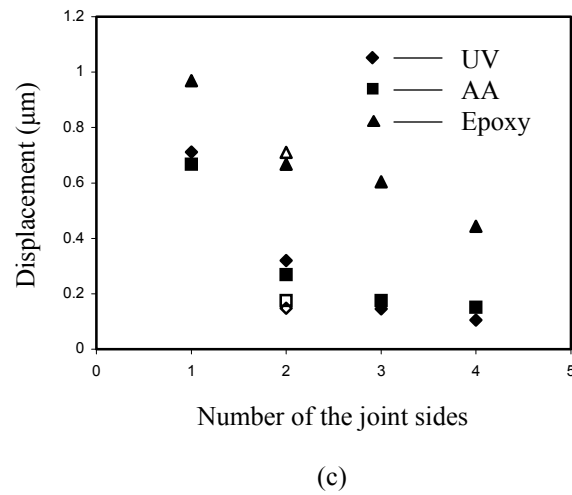
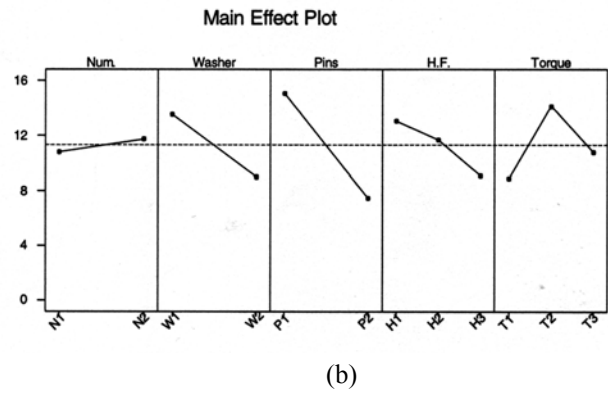
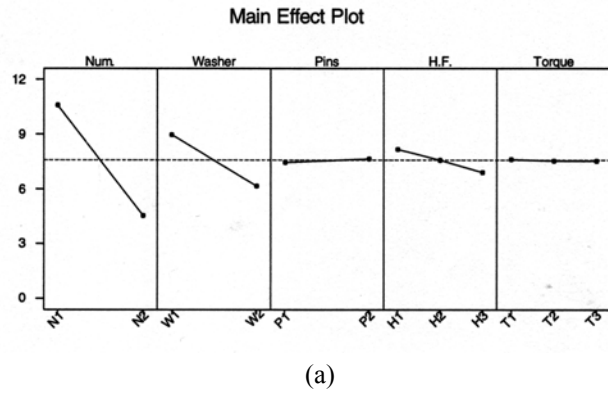


Fig. 1. (a) Main effect plot for  $\overline{\Delta l_0}$ ; (b) Main effect plot for  $\overline{\Delta \theta_0}$ ; (c) The displacement of side joint for different joint sides, the hollow markers present the displacement of two-symmetry side joint corresponding to different glues; (d) The variation of the displacement of piece 1 at z direction for lap joint at different gaps; (e) The relationship of the rotation angle of piece1 and initial inclined angles with constant average distance between two pieces.