

# LASER WELDING APPLICATION IN CAR BODY MANUFACTURING

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## ABSTRACT

Laser welding application for car body manufacturing has many advantages in the stiffness and the lightness of vehicle, the productivity of assembly line, and the degree of freedom in design. This presentation will express the innovation of car body manufacturing including parameter optimization, process modeling, and system integration. In this application the investment for systems was cut down dramatically by real time switching over the laser path between two welding stations. Points of technical discussion are as follows: optimization of parameters such as laser power, robot speed and trajectory, compact and useful design of jig & fixture to assure welding quality for 3 sheet-layer zinc-coated steel, system integration between 4kW Nd:YAG laser device and the other systems, on-line real time welding quality monitoring system, perfect safety standards for high power laser, minimization of consumption costs such as arc lamp, protective glass for optic, etc.

Laser welding has found a place on Hyundai's production plant in conjunction with the startup of mass production of new sports car, and this production system is the result of a collaboration of its engineers. Outer side sheets are joined to inner side sheets by 122 stitch welds totally. And the length is about 2.4meter.

## KEYWORDS

Laser welding, Nd:YAG laser, parameter optimization, system integration

## 1. Introduction

Most automotive companies make use of resistance spot welding in order to assemble car body. Generally car body has almost 5,000 spot welding points. Even though spot welding has been progressed for last 60 years, there were some limitations in upgrading production line. So instead of conventional spot welding it is time to start a new technology for the future.

Laser welding has many advantages in car body manufacturing. Thanks to fast speed, it can reduce the number of welding stations of car body assembly line. And also with non-contact & one-side approach, it is possible to design various car body structures. Maybe laser welding can free car designers from box structure for spot welding. It means that we can reduce the weight of body by optimized design. There is another reason that we cannot help choosing laser welding. That's a perfect joining method. In order to increase strength of body and decrease weight of body automotive companies have developed new technologies such as hydroforming, aluminum & magnesium alloy, plastic. We don't find perfect joining method except laser welding, which can join hydroforming parts or these materials. So we have developed laser welding for car body for a long time. But laser welding was not sufficient to substitute for spot welding. Because it is very difficult to assure welding quality of zinc-coated steel in mass production and it needs more money than spot welding[1]. This study shows the solution to overcome the problems.

## 2. Parameter Optimization

Laser welding can make flexible trajectory because it is a non-contact method as compared with conventional welding. In order to realize superior merits of laser welding we have tested a great number of welding patterns shown at Fig. 1 and selected the best pattern[2].

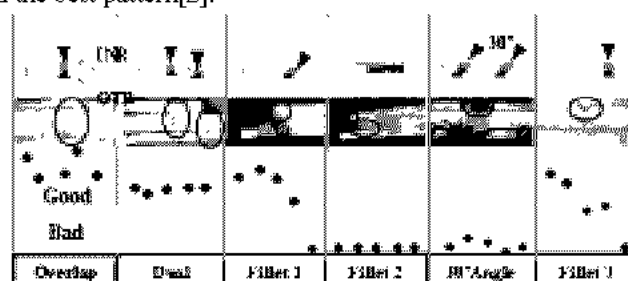


Fig. 1 Comparison of welding patterns for Nd:YAG laser

Laser welding system based on Nd:YAG laser consists of various parameters such as laser power, velocity of 6-axis industrial robot, focal position of laser beam, the gap between sheets, and the number of sheet layers. Parameters are shown in Table 1.

Fixed Value	Level 1	Level 2
Steel Type of Panel	Mild	Zinc-Coated
Sheet Layer(2/3)	0.7+0.7	1.2+1.4+0.7

Variable(2 sheet-layer)	Level 1	Level 2	Variable(3 sheet-layer)	Level 1	Level 2
A.Laser Power(kW)	2.0	2.7	A.Laser Power(kW)	3.0	4.0
B.Velocity(mm/s)	60	100	B.Velocity(mm/s)	28	35
C.Focal Position(mm)	0.0	4.0	C.Focal Position(mm)	0.0	4.0
D.Gap between Panels(mm)	0	0.2	D.Gap between Panels(mm)	0	0.2+0.2

Table 1 Welding parameters for Nd:YAG laser

After finishing the experimental design through Taguchi method, we made use of experimental device shown in Fig. 2.

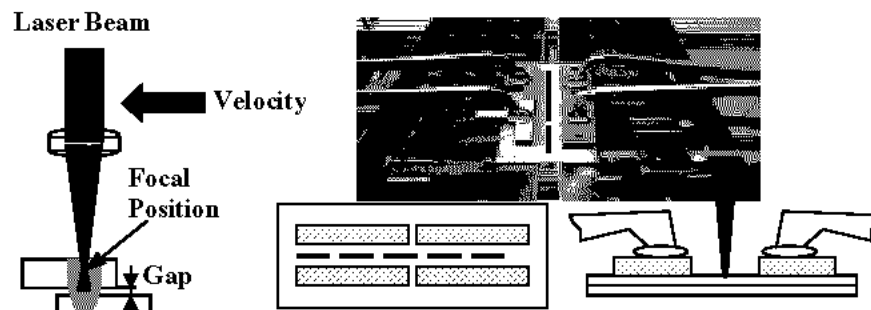


Fig. 2 Setup of the experimental system

As the result of interaction between factors, we can know that there is an independent relationship between A(Laser Power) and B(Velocity) and there are dependent relationships between A(Laser Power) and D(Gap), between B(Velocity) and D(Gap), in Fig. 3. Taguchi L8 orthogonal array in Table 2 was designed in consideration of interaction between factors.

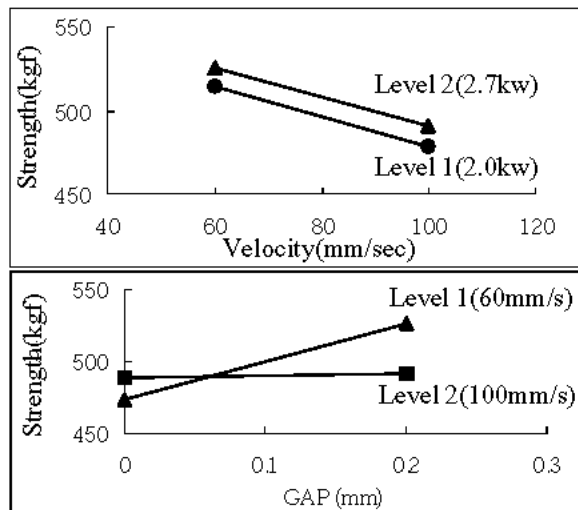


Fig. 3 The interactions between B and A, D

Expt. No.	Factor						
	A	B	C	D	A × D	B × D	-
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

Table 2 Taguchi L8 orthogonal array

Eq.(1) is S/N ratio for performance of Larger-the-better in order to obtain robust factor level which minimizes the effect of noise and maximizes the strength of welding[2].

$$S/N \text{ ratio} = -10 \log_{10} \sum (1/y_i^2)/n \quad (1)$$

We calculate variance analysis of overall factors, interactions, and errors from S/N ratios. And contributions( $\rho$ ) of factors are defined by Eq.(2) ~ Eq(4).

$$\rho_{\text{factor}} = (S'_{\text{factor}} / S_{\text{overall}}) \times 100 \quad (2)$$

$$\rho_{\text{interaction}} = (S'_{\text{interaction}} / S_{\text{overall}}) \times 100 \quad (3)$$

$$\rho_{\text{error}} = \rho_{\text{overall}} - \sum \rho_{\text{factor}} \quad (4)$$

As the result of analysis, the most effective factor is B(Velocity), 51.6%. The next things are A(Laser Power), 25.8% and C(Focal Position), 15.8%. As the result of optimizing the factors which can minimize the effect of noise and variability simultaneously, the best conditions are level 2(2.7kW) of A(Laser Power), level 1(60mm/s) of B(Velocity), and level 1(0.0mm) of C(Focal Position). In the case of these parameters optimization, the expected result of welding strength shows the expected value is 27% higher than the non-optimized. In order to make the standards of welding specification we have tested 22 combinations of sheets that were applied to laser welding in mass production.

### 3. System Overview

It is very difficult to design the system based on laser device because of its specialty. In the plant of car body manufacturing the process of laser welding has different configuration from the process of resistance spot welding. The laser welding system consists of six components: 1.6-axis industrial robot with optic head which can focus laser beam irradiated from laser source, 2.4kW Nd:YAG laser device, 3.Beam delivery system which can transmit laser beam with fiber cable from in-coupling of laser device to out-coupling of optic head, 4.Jig & fixture system which can control the gap tolerance between sheets in order to assure welding quality, 5.On-line welding quality monitoring system, and 6.Common communication network protocol to integrate systems with different communication networks. For the best welding performance we need to select optimal devices and designs for systems.

In order to increase productivity of laser welding, we designed stitch pattern, which had welding distance of 20mm and moving distance of 30mm repeatedly. So welding robot needs three requirements: 1.The performance of acceleration and deceleration in very short pitch of stitch pattern, 2.The performance of uniform velocity in 20mm of welding distance to keep welding quality from outside disturbances, 3.The accuracy of trajectory and repetition to maintain focal position of laser beam within the tolerance that can have good welding. We tested outstanding industrial robots from several makers, but we could not find perfect robot that satisfied all conditions. Therefore we selected the best robot based on Fig. 4. And also useful sequence program was developed to solve the problem that the start and end points of welding line had bad quality due to the limitation of robot dynamics.

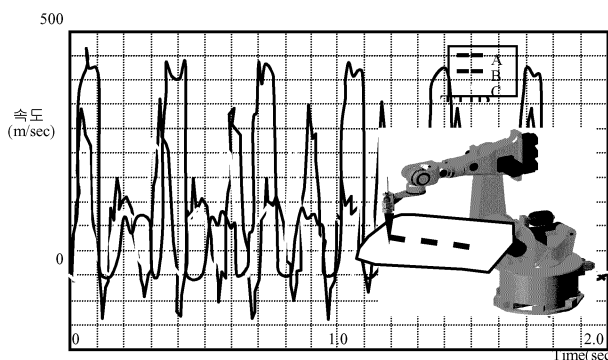


Fig. 4 The velocity performance

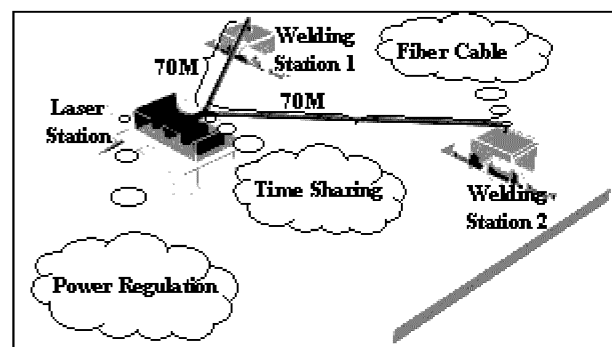


Fig. 5 Structure guideline for Nd:YAG laser system

Nd:YAG laser has a good merit to transmit laser beam through fiber cable regardless of the distance. Because most automotive factories are full of many kinds of facilities, we should make use of the merit. So we installed the laser device far away from the welding station. Fig. 5 shows how to install laser welding system. There are four robots in two welding stations and two laser devices in one laser station. As shown in Fig. 5, laser beam is generated by the laser device of 4kW Nd:YAG and transmitted by fiber cable(70m) from laser station to welding station. After that, side panel is welded by laser beam which is controlled by time-sharing. The laser device needs good performance because it should rapidly control the sequence of time-sharing all day long.

In Fig. 1, the geometry of welding joint was chosen as overlapped joint. According to another reports[3], there were two contrary problems. In the case of wider gap than tolerance between sheets, the gap gave rise to undercut or separation of welded area due to non-contact approach of laser welding. On the contrary, in the case of zinc coated steel, no gap between sheets gave rise to porosity and poor surface quality. The zinc coatings at the interface of two-coated sheets vaporize during welding because the boiling point of zinc gas (900~910℃) is lower than the melting point of steel(1400~1500℃). If there is no vent to escape zinc gas, zinc vapor cannot help leading to expulsion of molten metal. It is essential to allow zinc to outgas in welding zinc-coated steel. The

present solution to these contrary problems is to control the gap between sheets. Usually the gap is in range of 0.1 and 0.2mm, depending on the type of steel and coating, the thickness of sheet and coating, etc. Fig. 6 shows the results of welding quality using 4kW Nd:YAG laser, respectively. It means that jig & fixture to control the geometry between sheets has to assure a little gap instead of no gap. Laser welding demands the tight tolerance. Reliable welding results are no longer guaranteed if the clearance between sheets is not proper. It is very difficult to maintain controlled gap in mass production line. Jig & fixture is the very solution as shown in Fig. 7.

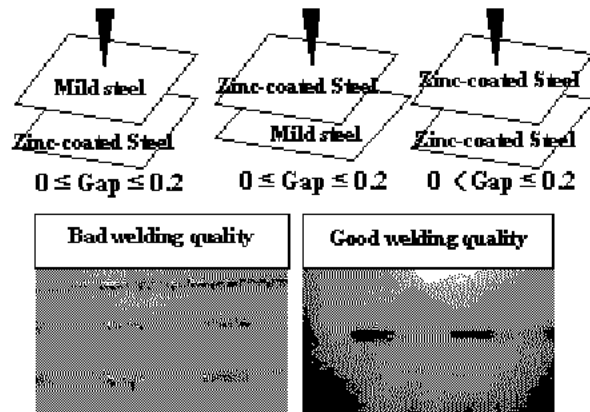


Fig. 6 The influence of gap between sheets

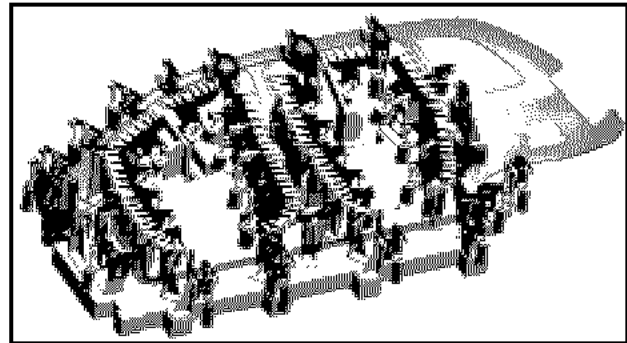


Fig. 7 Jig & fixture for controlled gap

The quality in conventional welding has been checked by inspection of post-welding. But in laser welding it is possible to measure whether welding quality is good or not automatically[4]. This page explains practical procedures and monitoring technique that can achieve quality assurance and perfect control. As laser welding starts, the process radiation reflected through the welding optics and fiber cable is mapped on the sensor mounted inside the laser device. The defined spectral range of the process radiation conducted through the optical wave guide is optically filtered and transformed into an electronic signal by means of detector that is proportional to the capacity of the process radiation. Then this signal is fed to the computer through signal processing device after pre-amplification and filtering. After that, process signal evaluated through software is displayed as specific output. On the basis of real signals in good quality, reference signals divided into average signal, lower limit signal, and upper limit signal are selected by analyzing correlation between quality and signal. If real signal exceeds limit value, there can be a bad quality as shown in Fig. 8. The stored welding data is recorded as file to establish database every welding cycle.

#### Weldability transverse cross sections of a weld profiles

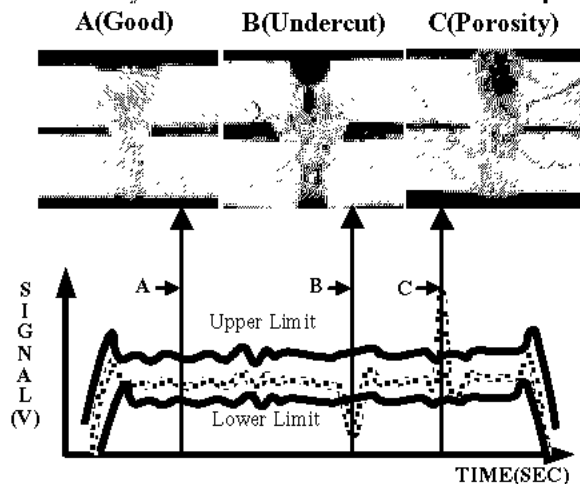


Fig. 8 The principle of inspection for laser welding

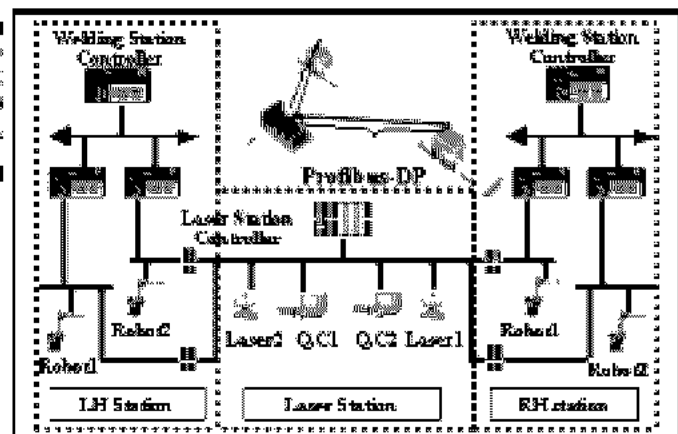


Fig. 9 The configuration for system integration

Not only system integration itself but also total system integration for all systems is needed to launch laser welding system into mass production line. Especially common communication network protocol is essential to system integration, which have a variety of communication specifications and request rapid processing speed in networking. The main principle is shown in Fig. 9(system structure for welding stations operated by Profibus-DP).

#### 4. Results

Passive safety, which has come to play an important role in designing vehicle increasingly, is one of the major reasons for introduction of laser welding application in production line. To prove that the laser-welded body can obtain higher performance than the spot-welded, necessary tests including collision were performed in 5 car bodies. As the result, laser-welded car satisfied the requirements of safety and performance as shown in Fig. 10.

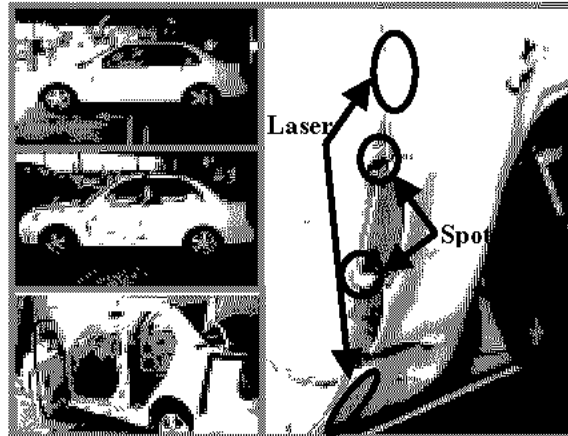


Fig. 10 The result of collision test by side impact

In 2001 two new models assembled by laser-welded side body panel launched into mass production. The total length of laser welding was about 2.4m and the combination of welding parameters consisted of 22 conditions. The range of welding rate for the conditions including thickness(1.6mm ~ 4.0mm) was 2m/min ~ 4.8m/min. Fig. 11 shows laser-welded part.

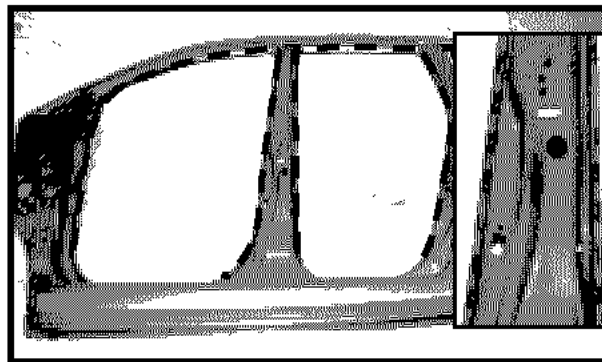


Fig. 11 The laser-welded line in side panel

#### 5. Conclusions

This paper shows the last goal of this study is manufacturing technology in car body plant exchanges the solution based on resistance spot welding for the solution based on laser welding. The conclusions can be summarized as follows:

- (1) In laser welding, it is difficult to optimize parameters because it is more sensitive than the other welding methods. Testing many combinations of sheets by Taguchi method, we could establish database for laser welding conditions successfully.
- (2) Welding quality depends on performance of systems including robot, laser device, jig & fixture, and communication network. At first, each system is designed for best performance respectively, and then all systems are integrated by robust design of hardware and software to cope with full operation all day long.
- (3) The vehicle made by laser welding satisfies safety criterion.
- (4) On-line automatic quality monitoring system improves the level of quality management.

All in all, this laser application has worked well in the production line and generally been an unqualified success. Around 300 side panels are currently being welded by laser daily at Hyundai Ulsan plant. It is certain laser welding is not optimal but obligatory in future automotive industry.

### References

- [1] W. M. Steen : *Laser Material Proceeding*, Second Edition, Springer, 1998, p.108 ~ 144.
- [2] Madhav S. Phadke : *Quality Engineering Using Robust Design*, Prentice Hall, 1989, p.97 ~ 132.
- [3] Mariana G. Forrest and William A. Marttila : *A Study of Effect of Laser Welding Process Parameter Variation on Weld Quality for Zn-coated Thin Auto Body Sheet Material*, ALAW(Automotive Laser Applications Workshop), 1996.
- [4] J. Mommsen and M. Stuermer : *Recent Development in Process Monitoring and Data Management for Laser Welding*, EALA(European Automotive Laser Application), 2001.