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A Study on the Weldability of AHSS_590MPa(Advance High Strength Steel) by Nd:YAG Laser Stitch Welding

Graduate School of Chosun University

Department of Mechanical Engineering

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고장력강판 (AHSS_590MPa)의
Nd:YAG Laser Stitch 용접에 관한 연구

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ABSTRACT

고장력강판 (AHSS_590MPa)의 Nd:YAG Laser Stitch 용접에 관한 연구

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최근 자동차업계는 연비향상, 환경오염 및 충돌안전 규제강화 등에 대한 법적규제의 강화에 기초하여, 기존의 주행성능 향상 및 배기량 대형화 등에 초점을 맞춘 신차 개발의 관점에서 탈피하여 이산화탄소 배출이 적고 연비가 대폭 향상된 친환경 자동차의 개발에 몰두하고 있다. 또한 자동차 산업은 총매출 120조, 총고용 9%, 수출총액의 13%를 차지하는 주력 기간산업으로, 매출 중 완성차 및 부품 제조업체의 매출 비중이 거의 동등한 구조로 되어있으며, 부품 제조에 필수적인 용접·접합기술과 같은 생산기반기술에 대한 의존도가 매우 높은 산업이다. 그래서 현재는 차체경량화 및 이와 관련된 기술은 연비와 이산화탄소 배출을 동시에 개선할 수 있는 가장 효과적인 방법이며,

전기자동차, 클린디젤자동차 및 연료전지자동차와 같은 모든 미래형 친환경 자동차에 공통으로 적용될 수 있는 공통핵심기술임에 틀림없다.

차체의 경량화를 위해서 Al, Mg합금과 같은 경량금속의 적용이 적극 검토되고 있는 가운데, 경량화와 함께 저비용 생산구조이면서 승객의 안전성을 동시에 충족시킬 수 있는 고장력강(AHSS: Advanced High Strength Steel)의 개발이 포스코를 중심으로 진행되고 있으며, 현대기아자동차를 비롯한 완성차 업체를 중심으로 고장력강을 적용한 부품 제조를 위한 선행연구가 진행되고 있는 상황이다. 그리고 자동차용 고장력강의 수요는 향후 폭발적으로 증가할 것으로 예상되며, 특히 현재 주로 사용되고 있는 400MPa 전후의 강재는 근시일 내에 600MPa~1GPa 급의 고장력강으로 대체될 것으로 업계의 전문가들은 예상하고 있고, 2015년에는 그 점유율이 80%에 육박할 것으로 예상하고 있다.

그러므로 주력 기간산업인 자동차 및 관련 부품산업을 발전시키고 글로벌 경쟁력을 선점하기 위해서는 향후 수요의 폭발적 확대가 확실시 되는 고장력강에 대한 새로운 개념의 용접/접합 기술개발이 절실히 요구되어 진다. 또한 현재 국내 자동차 차체에는 일반강에서 AHSS까지 다양한 강종들이 적용이 시도되고 있으며, 경량화를 위해 더욱 선진화 된 AHSS 강종을 적용하기 위해 철강업체들의 연구 개발이 가속화되고 있다. 하지만 이러한 AHSS 강종을 적용하기 위한 용접법은 선진국에 비해 상당히 낙후되어 있는 실정이다.

특히 자동차 산업에서의 기존 저항 점용접에 의하여 도장도금강판을 용접시 도장/도금이 녹아 비산되어 접합하고자 하는 부위를 오염시키므로 용접불량이 많이 발생하나, 레이저 스티치 용접을 적용하면 이러한 문제점이 없을 뿐만 아니라 용접장의 길이가 상대적으로 길어 용접강도가 증가하며 상이두께의 용접도 가능하다.

이에 따라, 본 연구에서는 자동차용 AHSS급 강재 DP590에 대한 레이저용접특성을 알아보고자 Nd:YAG 레이저 스티치 용접을 실시하고 용접성, 용입현상, 미세조직 및 경도 그리고 인장특성 및 강도에 미치는 공정변수에 대한 영향을 평가하고자 한다.

Chapter 1

INTRODUCTION

1.1 Research Background & Purpose

Recently from the automatic industry is caused by with continued ratio improvement and, CO_2 environmental regulation and demand of crash safety reinforcement etc. from the world-wide automobile advanced various nations leads a continued these rules and celebration of the environmental characteristic automobile development which hits the high performance and the research and development for a body lightweight and is in parallel and productivity improvement technical etc. is research and development continuously.

Specially body lightweight is not only the environmental contamination improvement which originates to a stack gas decrement development for the efficient improvement of the future fuel cell automobile which will be completed from the lightweight technical development earnestly is more demanded within 5 years.

Accordingly, lightweight non-ferrous materials (aluminum alloy, magnesium, and special reinforced plastic), but the cost of increased coverage, welding strength has a lot of problems to be solved in terms.

In response to recent automotive parts industry for safety apply the existing strength (HSS; high strength steel) compared to the strength and forming new advanced high strength steel excellent (AHSS; advanced high strength steel) body parts to develop and apply for the technology development is underway.

However, if the developed strength steel due to its characteristics, such as complex shape and Formability spring back effect due to a problem have a problem with body parts, and recently secured their material strength and elongation of the TRIP (transformation induced plasticity), TWIP (twinning induced plasticity) steel, and hot stamping, etc. have been developed mainly applied in the European car market has increased gradually in North America, Japan's becoming its application.

AHSS compares in the general mild steel and the alloy addition quantity increases and the welding quality differs with automatic AHSS development together research earnestly is demanded about the technique which is various for a welding quality and a welding characteristic improvement.

This high accessibility of the laser welding head, faster welding speeds and have superior weld quality, So by using laser welding vehicle body assembly line, reducing the number of cells at the same time improving the strength of body and body weight reduction, fuel efficiency improvement, cost savings can.

Accordingly, the present study AHSS automotive grade steel to evaluate the characteristics of laser welding for the Nd:YAG laser welding and welding performed, weldability, hardness and tensile properties and process parameters on the intensity is to evaluate the impact on.

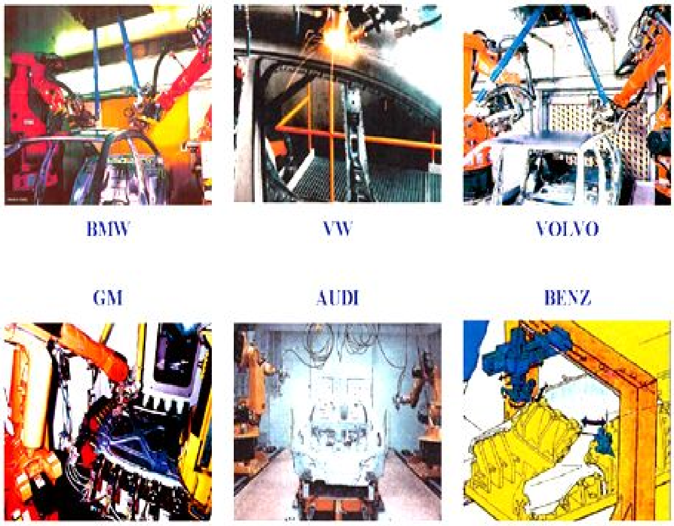


Fig. 1.1 Application of Laser Welding in the car body assembly

1.2 Research Methodology

In this study, Nd:YAG Laser Stitch Welding After selecting the optimum welding conditions, welding conditions selected for the one point weld (KS B 0851) standard tensile tests are conducted based on the shear strength and tensile loads on the basis of Nd:YAG Laser Stitch determined the optimal length of weld bead.

Investigates the pitch of the welding department spot welding from the actual automobile and after deciding the length of laser stitch welding department pitch respectively with 40mm, 50mm and 60mm, tensile-shear test about the specimen in standard, about Nd:YAG Laser Stitch welding department pitch.

In this experiment, Nd:YAG Laser Stitch Welding equipment used to condition selection 3KW grade Nd:YAG laser welding using a Laser Power, Welding Speed as a variable and, Focal Depth and +1 mm, Shielding Gas and Argon 15ℓ/min were welded to. Weld bead surface, as well as photographs selected by the state and Spot Welding using a specimen of the same size as the 10mm, 15mm, 20mm welded tensile tests were conducted, each Nd:YAG Laser welding of the beads determines the length of Stitch was.

The pitch of Nd:YAG Laser Stitch welding department 30mm to pile up the multi spot welding specimen (DP590) at 300×100×1mm sizes and produce, the spot welding department pitch of the actual automobile pitch of the spot welding to investigate, hold an examination of tensile-shear test.

At the size which is identical with the multi spot welding specimen and Nd:YAG Laser Welding Conditions for Selected Stitch weld bead size of the weld was 20mm. And pitch for 40mm, 50mm, 60mm and a tensile test after applying, the multi spot weld tensile loading and shear strength according to the Nd:YAG laser welding of Stitch pitch were determined.

In addition, the thermal camera using a Heat Distribution Test and WZ, HAZ, BM Hardness Test was measured on.

1.3 Recently Technology Trends

In recent years, automobile weight and acceleration of research and development for high-temper parallel High Strengthening of the body, light weight, increase productivity, technology and research and development is ongoing. Therefore, the conventional resistance spot welding based on the cost of a car design and production methods, technological limitations and lightweight body, improve safety, increase productivity, to achieve the TB (Tailored Blank) applies light laser welding technology and 3-D laser welding technology in the automobile industry has emerged as a key technology.

Automotive industry since the 1960s, Ford's mass production of a car and two second oil shock increased demand for lighter cars were going through. The demand quality changes about the automobile and in order to correspond in automobile lightweight decreases the thickness of the steel with the plan which reduces a body weight and the steel which raises the strength, the namely AHSS or UHSS will applyment quickly, is developing.

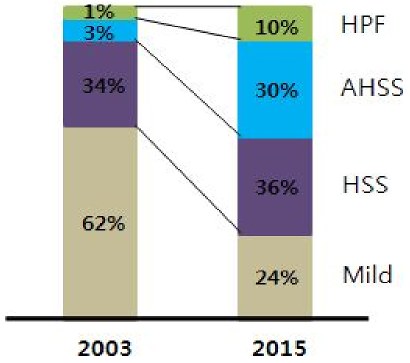


Fig. 1.2 High strength steel demand forecasting

Therefore, resistance spot welding, welding technology since the 1980s, to obtain high-quality welds while also improving productivity, the application of laser welding can be started. Laser output, especially the growing automotive engine parts and mission began to be applied to the laser welding process is required since the 3-Dimensional car body and electric parts, etc. have been increasingly applied.

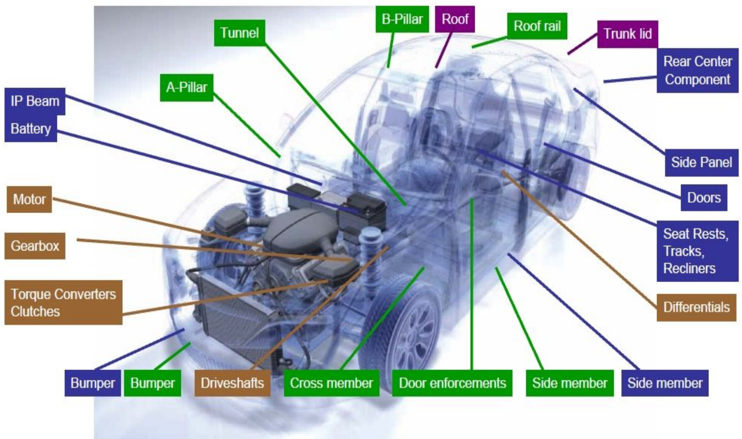


Fig. 1.3 Laser Welding applications - Automotive Industry in details

In developed countries in 1995 to produce automotive body parts applied in laser welding technology, industrial robots, articulated Nd: YAG laser head mounted on the welding flange welding Spot welding technology compared to conventional welding time by 45% by reducing has made to improve the productivity boost.

However, the Nd:YAG laser welding, the system's investment in comparison with the existing six times more expensive because of the welding machine, production line does not apply to the situation is rapidly expanding.

Therefore, Spot welding productivity over five times more than the minimum welding technology, laser marking device is used in the scanner (Galvanometric Scanner) and robotic laser welding technology in the leading foreign car maker is considering applying to developed and some parts, domestic car technology development in industry, it is required for the system because the manufacturing industry to develop robot-based remote laser welding technology has emerged as an important task.

Domestic auto production line, most of the resistance spot welding, and automotive manufacturers around the institute of aluminum alloy, high tensile strength materials such as applying for a welding, bonding technology in the previous studies are in progress.

Already in Europe and CONCACAF, the Japanese auto industry in the high tensile strength by performing laser welding vehicle body assembly line, reducing the number of cells at the same time improve body strength and light weight of the body is recently developed and developing of ultra high strength steel plate joining technologies for the application of basic research is underway.

Chapter 2

THEORETICAL BACKGROUND

2.1 Principles and characteristic of Nd:YAG Laser Welding process

2.1.1 Principles of Nd:YAG Laser Welding

The Nd:YAG Laser is one of the most versatile laser sources used in materials processing. The relative robustness and compactness of the laser and the possibility for the 1.06 micron light it produces to be transmitted to the workpiece via silica optical fibres, are two features which contribute to its success. Nd:YAG Lasers were first commercialised operating mainly in pulsed mode, where the high peak powers which can be generated were found useful in applications such as drilling, cutting and marking. These pulsed lasers can also be utilised for welding a range of materials. More recently, high power (up to 10KW), continuous wave (CW) Nd:YAG Lasers have become available. The Nd:YAG crystals in these lasers can be pumped either using white light flashlamps or, more efficiently, using laser diodes. The latter methods are used to produce high quality beams, which can be focused to smaller spots (and therefore produce higher power densities) than the flashlamp pumped lasers. Because of the possibility of using fibre optic beam delivery, these lasers are often used in conjunction with articulated arm robots, in order to work on components of complex shape.

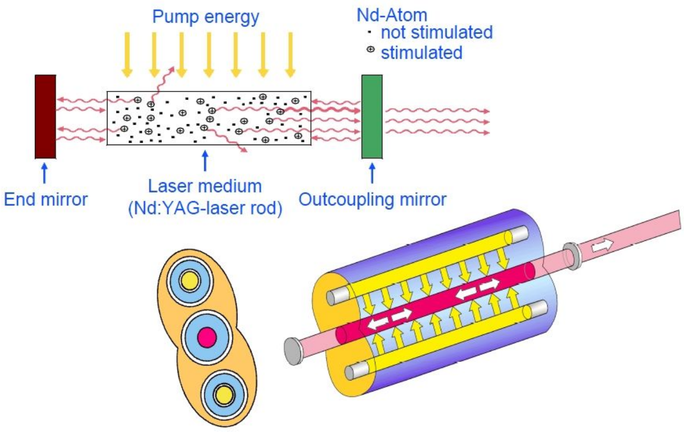


Fig. 2.1 Principles structure of a Nd:YAG Laser

Because of the wide range of applied power and power densities available from Nd:YAG Lasers, different welding methods are possible. If the laser is in pulsed mode, and if the surface temperature is below the boiling point, heat transport is predominantly by conduction and a conduction limited weld is produced. If the applied power is higher (for a given speed), boiling begins in the weld pool and a deep penetration weld can be formed. After the pulse, the material flows back into the cavity and solidifies.

Both these methods can be used to produce spot welds. A seam weld is produced by a sequence of overlapping deep penetration 'spot' welds or by the formation of a continuous molten weld pool. For the former, once the energy input is sufficient to ensure that the weld does not solidify between pulses, the 'keyhole' type weld normally associated with CO_2 laser welding can be formed. Pulsed laser welding is normally used at thicknesses below about 3mm. Higher power 4-10kW CW Nd:YAG Lasers are capable of keyhole type welding in materials from 0.8mm (car body steel) to 15mm (ship steel) thickness.

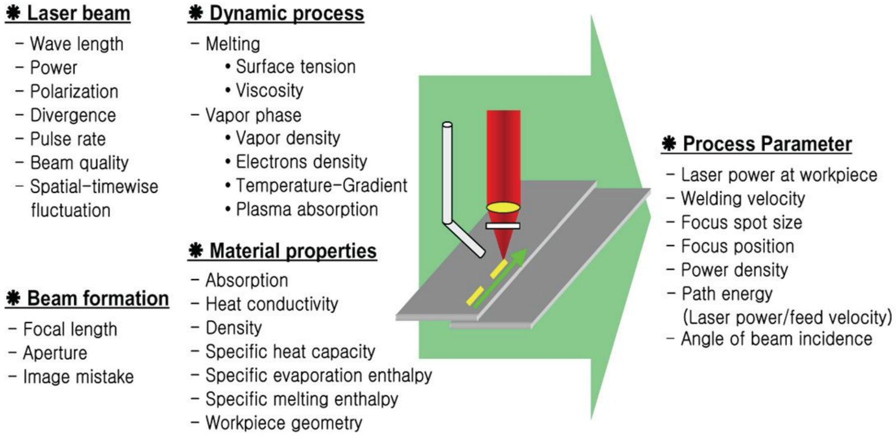


Fig. 2.2 Important influential variables of Laser Welding process

Nd:YAG Laser welding is used commercially on a wide range of C-Mn steels, coated steels, stainless steels, aluminium alloys, titanium and molybdenum. The low heat input welding offered by Nd:YAG Lasers is utilised in the electronics, packaging, domestic goods and automotive sectors, and significant interest has been shown more recently, particularly for the high power CW lasers, in the shipbuilding, oil and gas, aerospace and yellow goods sectors. Important R&D issues involve development of high power lasers of better beam quality, use of distributed energy in the beam focus, weld quality maintenance for both thick and thin sections and weld classification.

2.1.2 Characteristics of Nd:YAG Laser Welding

1) Advantages of Nd:YAG Laser Welding

- The laser beam welding process produces narrow fusion and heat-affected zones, minimal shrinkage and distortion
- Weld repeatability from part to part
- By using magnifying optics for alignments, accurate placement is possible
- It is a noncontact process - the beam needs only a line-of-sight to the weld joint
- Sections as thin as .025 mm (.001") can be successfully welded
- Welds are usually made directly in atmosphere using a shielding gas
- The laser beam is unaffected by magnetism
- No x-rays are generated by this process
- The laser beam can be time-shared among a number of workstations

2) Disadvantages of Nd:YAG Laser Welding

- Welding operations are, depending upon type, quite cost intensive.
- Very expensive as well is the welding additional material, due to minor production quantities. This particular disadvantage will be abolished due to the fact that, corresponding with the welding time only minor quantities are being applied.
- For an open and thus flexible handling technology, an isolated and correspondingly secured working room is necessary (laser protection).

2.2 Principles and characteristic of Resistance Spot Welding process

2.2.1 Principles of Resistance Spot Welding (RSW)

Spot welding is one of a group of resistance welding processes that involve the joining of two or more metal parts together in a localised area by the application of heat and pressure. The heat is generated within the material being joined by the resistance to the passage of a high current through the metal parts, which are held under a pre-set pressure.

The process is used for joining sheet materials and uses shaped copper alloy electrodes to apply pressure and convey the electrical current through the workpieces. Heat is developed mainly at the interface between two sheets, eventually causing the material being welded to melt, forming a molten pool, the weld nugget.
The molten pool is contained by the pressure applied by the electrode tip and the surrounding solid metal.

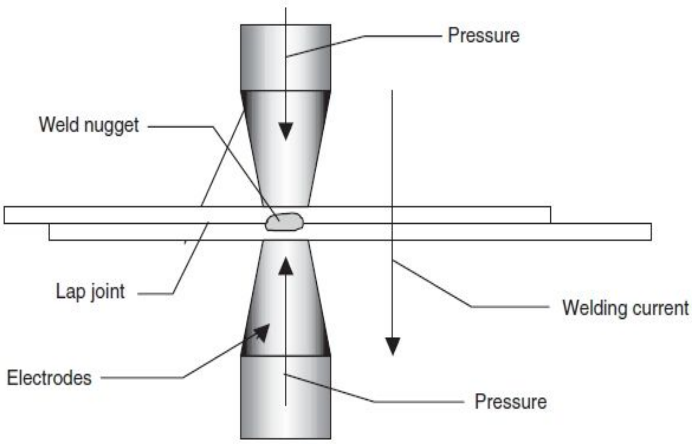


Fig. 2.3 Principles of Spot Welding process

Spot welding is one of the oldest welding processes. It can be used on very thin foils or thick sections but is rarely used above about 6mm thickness. It is used in a wide range of industries but notably for the assembly of sheet steel vehicle bodies where more than 100 million welds are made per day in Europe alone. High quality welds can also be made in stainless steels, nickel alloys, aluminium alloys and titanium for aerospace application.

But high strength and ultra-high strength steels, coated steels and aluminium alloys are of great interest to the automotive industry but can have weldability problems. Although the problems are understood, further improvements in weldability and electrode lives are still being sought. There are also limitations in the ability of spot welding to join sheet to tube, which need to be addressed.

2.2.2 Characteristics of Resistance Spot Welding (RSW)

1) Advantages of Resistance Spot Welding (RSW)

- High speed welding
- Easily automated
- Suitable for high rate production
- Economical

2) Disadvantages of Resistance Spot Welding (RSW)

- Lower tensile and fatigue strengths
- Lap joints add weight and material
- Cracks and Pin holes
- Electrode deposit on work
- Porosity or cavities
- Deep electrode indentation
- Improper weld penetration
- Surface appearance

- Weld size and Irregular shaped weld

2.3 Principle and characteristic of Laser Stitch Welding process

2.3.1 Principles of Laser Stitch Welding

The stitch welding is randomly in a way that welding Spot Welding of automotive welded at regular pitch, similar to the welding at regular pitch to doing Stitch is called welding.

Currently used in Europe as body welding and welding of sheet metal is widely used in Lap Joint. The stitch length of 20-30 mm is found on the basis of the experiment results and references. The pitch of stitches is set to be greater than 18 mm regarding strength and thermal stress.

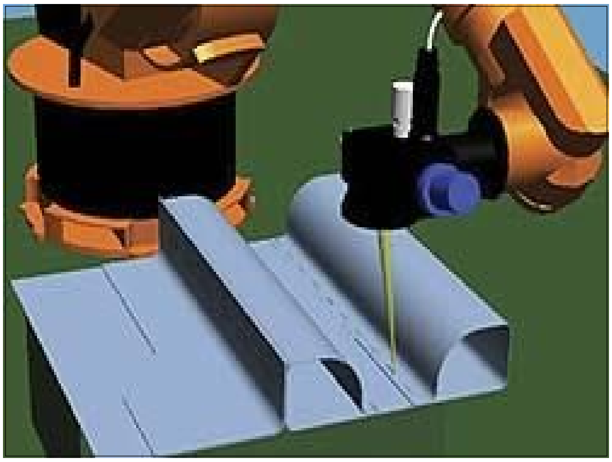


Fig. 2.4 Principles of Laser Stitch Welding process

Laser Stitch Welding of these, unlike the existing non-contact, so much the problem of the body and the tensile strength and accuracy, and innovative improvements to the welding groove width for the purpose of eliminating the need to increase the weight and design freedom is possible.

Also, the number of mold and weld locations due to the reduction and work process simplification can reduce vehicle assembly operations. (When applying laser welding process 2 ~ 3USD of costs and, 2 ㎏ may be lightweight and look at a rate of 10-20%)

The resistance spot welding of existing (resistance spot welding) one automobile plan and economic of productive method, will be able to overcome a technical limit with foundation. (There being a possibility of 50% or more of reducing the soluble area which is necessary to the welding of Laser stitch welding at the time of existing)

2.3.2 Characteristics of Laser Stitch Welding

1) Advantages of Laser Stitch Welding

- Thickness and material bodies of two kinds of Spot welding quality than the existing strength and weld quality is excellent and that will be can get.
- Unlike the current welding system welding operation takes place after the press molding materials useful in the design of low loss high.
- The number of mold and weld locations due to the reduction and work process simplification can reduce vehicle assembly operations.
- Design a high degree of safety is possible.
- The laser welding compares generally in existing welding method and

the precision is high and The welding speed is quick and there is not objective strain and the risk is low the noxious gas.

- welding is fast, and very good weldability, welding process can also be simplified in terms of production can expect a significant improvement compared.

2.4 Characteristics of Object Materials

The materials used for this study is DP590. To minimize the mechanical effect in welds such as contraction and expansion in weldment, specimens with dimension 30×10×1mm was made to conduct the welding experiment. And this used the standard which is seen clearly in KS B 0851.
Chemical composition and mechanical properties of base metals are given in Table 1.1 and 1.2 respectively.

Table 2.1 Chemical compositions in DP590

Material	Chemical Composition (Wt%)				
DP590	C	Fe	Mn	P	S
	0.128	0.263	0.015	0.037	2.554

Table 2.2 Mechanical properties of DP590

Material	T.S(N/mm^2)	Y.S(N/mm^2)	Elongation(%)
DP590	595	492	34.3

DP590 has high specific strengths and good elongation, and thus have been applied widely in the automobile. Study of welding structure characteristics is essential for its promotion and application.

2.5 Type of characteristics of AHSS (Advanced High Strengh Steel)

2.5.1 Type of Advanced High Strengh Steel (AHSS)

Advanced High Strength Steels are being developed for automotive applications. These automotive grades are different when compared with the conventional low and high strength steels. AHSS has superior mechanical properties which are developed in it due to the steel's structure and due to its distinct processing. AHSS is manufactured by adopting control cooling from austenite or austenite plus ferrite phase on the run out roller table in a hot rolling mill or in the cooling section of a continuous annealing furnace in cold rolled product.

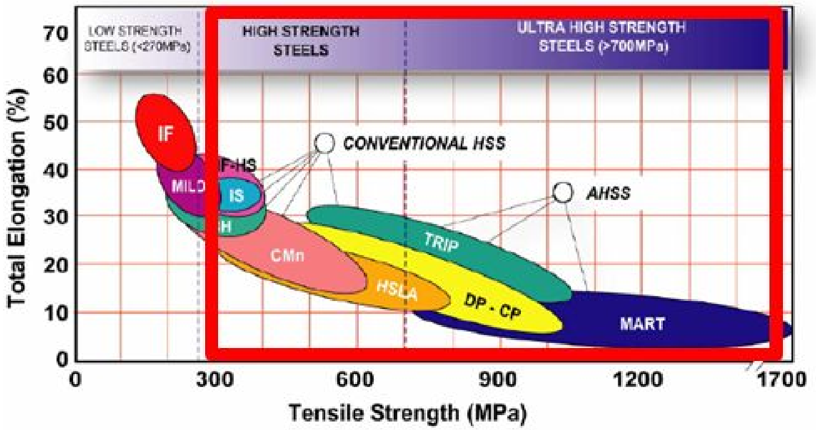


Fig. 2.5 Schematic of AHSS and UHSS steels

As a representative of the kinds of high tensile steel plate, the Dual Phase (DP) steel ,Transformation Induced Plasticity (TRIP) steel ,Complex phase (CP) steel ,Martensitic (MS) steel ,Twinning Induced Plasticity (TWIP) steel and so on.

So, Advnaced high strength steel can be reduction of car weight and fuel, emissions of hazardous substances is likely to contribute to.

2.5.2 Characteristics of DP590

Dual-Phase steel is a mixture of ferrite matrix and martensite decorating grain boundaries. Some have additions of bainite. The soft phase ferrite provides the ductility while the hard phase martensite offers the strength.

The steel having the combined phases appears to possess superior mechanical properties over conventional mild steels and high strength steels.

It therefore has quickly become one of the most popular and versatile materials in today's automotive industry.

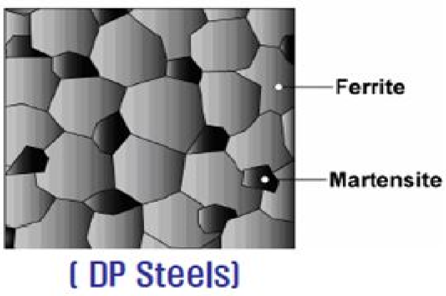


Fig. 2.6 Schematic of DP590

DP steel also has a bake hardening effect which is an important advantage. The hardening effect is the increase in the yield strength resulting from the elevated temperature aging after pre-straining. The degree of the hardening effect will depend on the specific chemistry and thermal history of the DP steel.

Carbon enables martensite formation at practical cooling rates in DP steel by increasing the steel hardenability. Chromium, manganese, molybdenum, nickel and vanadium when added individually or in combination, help also to increase the hardenability. Carbon, as a ferrite solute strengthener, also strengthens the martensite as done by silicon and phosphorus.

These additions are carefully balanced in DP steel for producing distinct mechanical properties as well as for maintaining superior capability for laser welding.

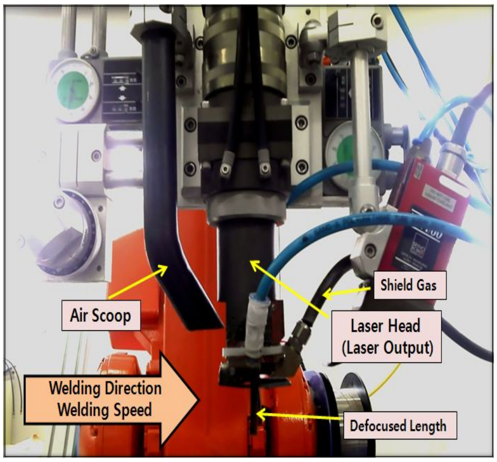
Chapter 3

OPTIMAL WELDABILITY OF LASER STITCH BY Nd:YAG LASER WELDING

3.1 Experimental work for Laser Stitch Welding

3.1.1 Nd:YAG Laser Welding equipment and experimental setup

To conduct experiment, Nd:YAG Laser Welding equipment (Trumpf HL3006D) used to condition selection 3KW grade Nd:YAG laser welding using a Laser Power, Welding Speed as a variable and, Focal Depth and +1 mm, Shielding Gas and Argon 15ℓ/min were welded to. Weld bead surface, as well as photographs selected by the state and Welding Spot Welding using a specimen of the same size as the 10mm, 15mm, 20mm welded tensile tests were conducted, each Nd:YAG Laser welding of the beads determines the length of Stitch was. Fig. 3.1 is shown the specification of Nd:YAG Laser Welding equipment (Trumpf HL3006D).



Manufacture Model	Trump Haas Laser HL3006D
Type	Nd:YAG Lamp Pumped
Max Output	4,000w
Laser Power	3,000w
Beam Quality	25
Laser Beam Cable (micrometers)	600

Fig. 3.1 Nd:YAG Laser Stitch Welding equipment in details

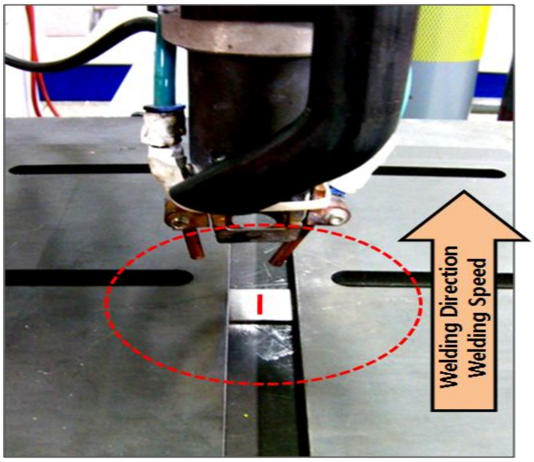


Fig. 3.2 Experimental setup for Nd:YAG Laser Stitch Welding process

3.1.2 Details of objective material

The chemical compositions and mechanical properties of the materials for DP590 used in the experiment are given at Table 3.1 Specimens of size 30mm(L) × 10mm(W) × 1mm(T) were made. (Table 3.2) The welding surface was wiped with Methyl Alcohol to remove the grease before welding process.

Table 3.1 Chemical composition and mechanical properties for DP590

<table>
<tr><td>Material</td><td colspan="30">Chemical Composition (Wt%)</td></tr>
<tr><td rowspan="5">DP590</td><td colspan="6">C</td><td colspan="6">Fe</td><td colspan="6">Mn</td><td colspan="6">P</td><td colspan="6">S</td></tr>
<tr><td colspan="6">0.128</td><td colspan="6">0.263</td><td colspan="6">0.015</td><td colspan="6">0.037</td><td colspan="6">2.554</td></tr>
<tr><td colspan="30">Mechanical properties</td></tr>
<tr><td colspan="10">T.S(N/mm^2)</td><td colspan="10">Y.S(N/mm^2)</td><td colspan="10">Elongation(%)</td></tr>
<tr><td colspan="10">595</td><td colspan="10">492</td><td colspan="10">34.3</td></tr>
</table>

Table 3.2 Dimensions of welded specimen

<Unit : mm>

Material	L	B	T
DP590	30	10	1

3.2 Experimental procedure

3.2.1 Nd:YAG Laser Stitch Welding condition

In this study, Nd:YAG Laser Stitch Welding After selecting the optimum welding conditions, welding conditions selected for the one point weld KS B 0851 standard tensile tests are conducted based on the shear strength and tensile loads on the basis of Nd:YAG laser Stitch determined the optimal length of weld bead.

Table 3.3 shows the Parameters of Nd:YAG Laser Stitch welding and Fig. 3.3 is shown the Laser welded specimen geometry for Tensile-Shear Test.

Table 3.3 Nd:YAG Laser Stitch Welding parameters

Welding Parameters	Index Values	Remarks
Laser Power (KW)	2.0, 2.5, 3.0	Robot Control
Welding Speed (m/min)	0.1 ~ 2.0	Robot Control
Focal Depth (mm)	+1	Robot Control
Shielding Gas (ℓ/min)	Argon 15 (ℓ/min)	-

3.2.2 The welding condition which follows in Bead-Size

In this experiment, Nd:YAG Laser Stitch Welding equipment used to condition selection 3KW grade Nd:YAG laser welding using a Laser Power, Welding Speed as a variable and, Focal Depth and +1 mm, Shielding Gas and Argon 15ℓ/min were welded to. Weld bead surface, as well as photographs selected by the state and Welding Spot Welding using a specimen of the same size as the 10mm, 15mm, 20mm welded tensile tests were conducted, each Nd:YAG Laser welding of the beads determines the length of Stitch was.

Table 3.4 Optimal Nd:YAG Laser Stitch Welding condition

Laser Power	Focal Depth	Welding Speed	Shielding Gas
3.0KW	+1 mm	0.3 m/min	Argon 15ℓ/min

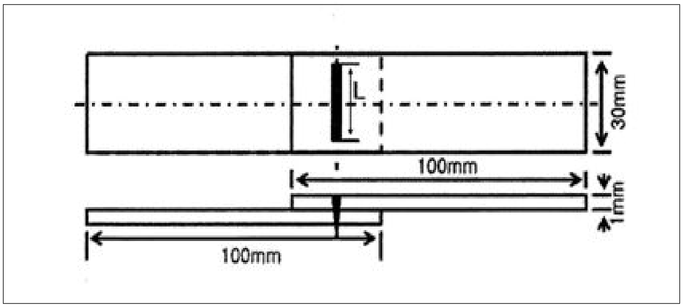


Fig. 3.3 Laser welded specimen geometry for Tensile-Shear Test
: L = 10mm, 15mm, 20mm _ KS B 0851

3.2.3 The welding condition which follows in Pitch-Size

The pitch of Nd:YAG Laser Stitch welding department 30mm to pile up the multi spot welding specimen DP590 at 300×100×1mm sizes and produce, the spot welding department pitch of the actual automobile pitch of the spot welding to investigate, hold an examination of tensile-shear test.

At the size which is identical with the multi spot welding specimen and Nd:YAG Laser Welding Conditions for Selected Stitch weld bead size of

the weld was 20mm. And pitch for 40mm, 50mm, 60mm and a tensile test after applying, the multi spot weld tensile loading and shear strength according to the Nd:YAG laser welding of Stitch pitch were determined.
*(Spot welding gap by Pitch: 1t per spacing of 18mm or more)

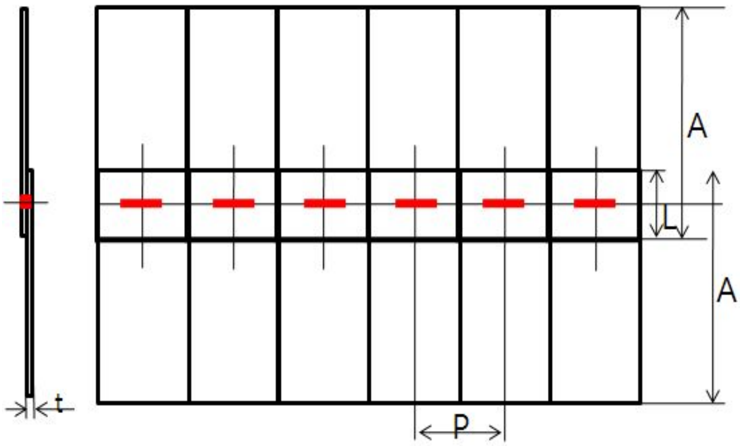


Fig. 3.4 Nd:YAG Laser Stitch welded specimen geometry in Pitch-Size
: P = 40mm, 50mm, 60mm

3.3 Evaluation of mechanical test

3.3.1 Tensile-Shear test

Tensile test was carried out with Dongil-Simaz Universal Testing Machine (EHF-EG200KN-40L) using WINSERVO program. Fig. 3.5 is shown the EHF-EG200KN -40L and tensile testing setup.
The specimens are fabricated in accordance with the korean standards (KS B 0851). The specimen dimensions are given in Table 3.5 Tensile test was done with Load speed 0.0833mm/sec and stress-strain curve was

obtained.

In general, the tensile elongation greater than 50% using 50mm/min, 50% less than if 5mm/min is used.

*(Elongation of DP590 : 34.3%, used 5mm/min)

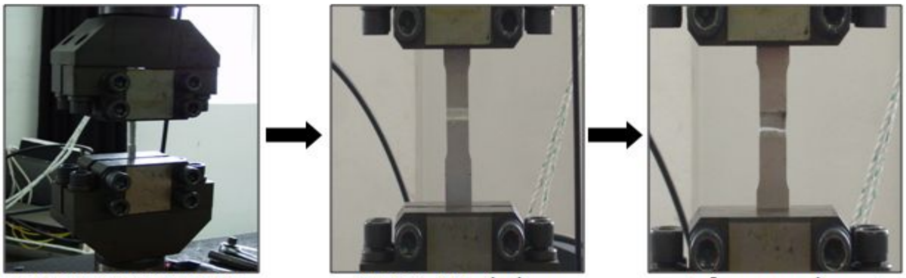
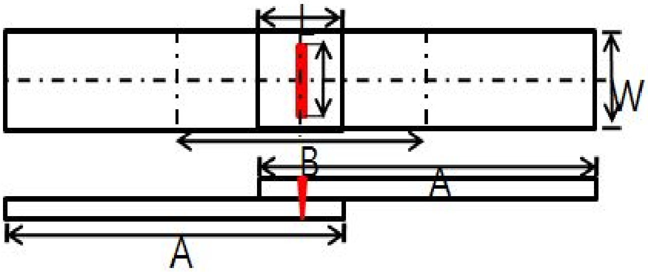


Fig. 3.5 Process of Tensile-Shear Test

	TYPE	Welding Speed(mm/min)
Rigid & Semi-rigid	I, II , III	5 ±2.5%
		50 ±10%
		500 ±10%
	IV	5 ±2.5%
		50 ±10%
		500 ±10%
	V	5 ±2.5%
		50 ±10%
		500 ±10%
Non-rigid	III	50 ±10%
		500 ±10%
	IV	50 ±10%
		500 ±10%

Fig. 3.6 Common rules of Tensile-Shear Test speed

Table 3.5 Dimension of Tensile-Shear Test specimen



Specimen STD. (KS B 0851)	Dimension (mm)			
	W	L	A	B
	30	30	100	90
Load Speed mm/sec	0.0833			

3.3.2 Hardness test

The hardness of welded specimen was measured using Akashi HM-112 Vickers Hardness tester as shown in Fig. 3.7. The indenter employed in the Vickers test was a square-based pyramid whose opposite sides meet at the apex at an angle of 136° with load 500g applied for 10 sec.
Fig. 3.8 is shown hardness measurement points of welded specimen. The hardness test was carried out on the welded specimen at 0.25 gap at three different positions at 0.4mm distance apart.

	Values
Type	Akashi HM-112 Micro vickers hardness tester
Load	0.5Kgf
Loading Time	10 sec.

Fig. 3.7 Micro vickers Hardness Tester

Fig. 3.8 Hardness measurement points of welded specimen

3.3.3 Heat distribution test

The high energy density laser welding heat source in a short time by the melting, solidification process, because the heat distribution experiment using a thermal imaging camera for the short-term temperature rise of the temperature and Heat Affected Zone(HAZ). The heat distribution of welded specimen was measured using Therma CAM_P25 tester as shown in Fig. 3.9. And Fig. 3.2 is shown heat distribution measurement points of welded specimen.

Product Specifications	
System Type	Focal Plain Array
Spectral Range	Long Wave
Detector	320 X240
Detector Material	Microbolometer
Measurement Accuracy	+/- 2 Degrees C
Measurement Range	-40 to 500 C
With Filter	500 C
Field View	24 X 18 Degrees
Cooling	Uncooled
Spatial Resolution	Lens Dependent
Thermal Sensitivity	<0.10 at 30 Degrees C
Detector Refresh Rate	60 Hz
Dynamic Range	14 Bit
Emmissivity Adjustment	.01-1.00
Palettes	Multiple
Display Type	LCD and Eye Piece
Image Storage Capacity	1000+ Images Per Card
Storage Medium	PCMCIA
Operating Temperature	-20 to 55C
Camera Weight	< 5.0 Lbs
Camera Size	8 X 6 X 4
Focus Distance	12 Inches to Infinity
Video Output	60 Hz NTSC
Power Supply	Battery or AC
Voice Annotation	Yes
Available Accessories	Lenses, PCMCIA Cards, Software, Batteries

Fig. 3.9 Spec of Therma CAM_P25

Chapter 4

EXPERIMENTAL INVESTIGATION & RESULTS

4.1 Optimal welding condition & bead shape

4.1.1 Experiment by Nd:YAG Laser Welding

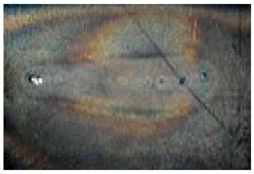
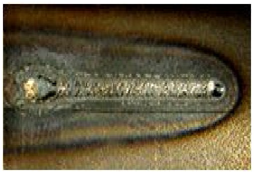
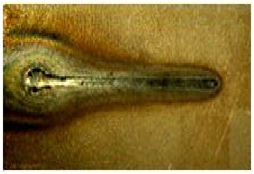
In this experiment, Nd:YAG Laser Stitch Welding equipment used to condition selection 3KW grade Nd:YAG laser welding using a Laser Power, Welding Speed as a variable and, Focal Depth and +1 mm, Shielding Gas and Argon 15ℓ/min were welded to. Welding conditions are shown in Table 4.1. Cross sectional view of the state and the weld bead surface through the proper welding conditions were selected.

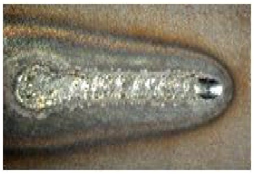
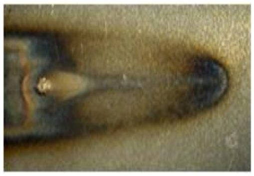
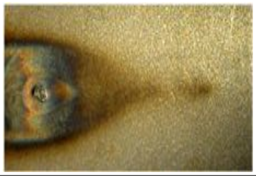
Table 4.1 Nd:YAG Laser Stitch Welding conditions

Laser Power	Focal Depth	Welding Speed	Shielding Gas
2.0, 2.5, 3.0KW	+1 mm	0.1 ~ 2.0 m/min	Argon 15ℓ/min

Table 4.2 and Table 4.3 of the selected welding conditions and weld bead surface and each of the cross sections and after Tensile-Shear test specimen.

Table 4.2 Bead Shape of Nd:YAG Laser Stitch Welds of each conditions

Welding Speed		Top Bead	Bottom Bead	Shear Strength (kN)
2.0KW	0.1m/min			7.68kN
	0.3m/min			6.88kN
	0.5m/min			6.23kN
	0.7m/min			5.87kN
	1.0m/min			5.69kN

Welding Speed		Top Bead	Bottom Bead	Shear Strength (kN)
2.5KW	0.1m/min			13.25kN
	0.3m/min			11.69kN
	0.5m/min			11.08kN
	0.7m/min			9.01kN
	1.0m/min			7.59kN

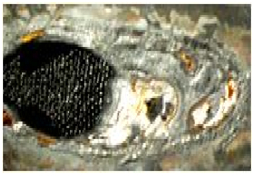
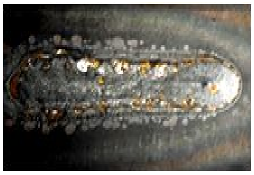
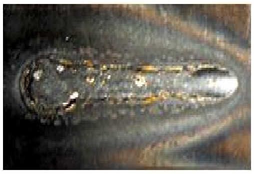
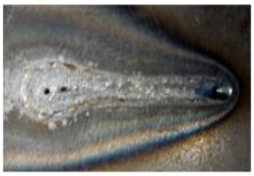
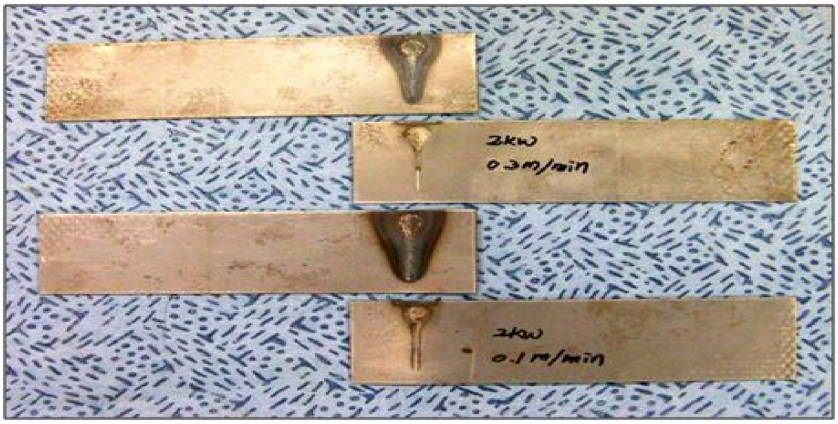
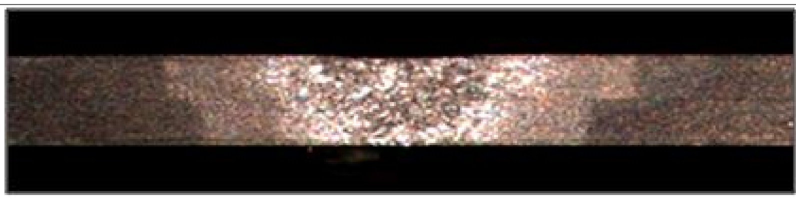
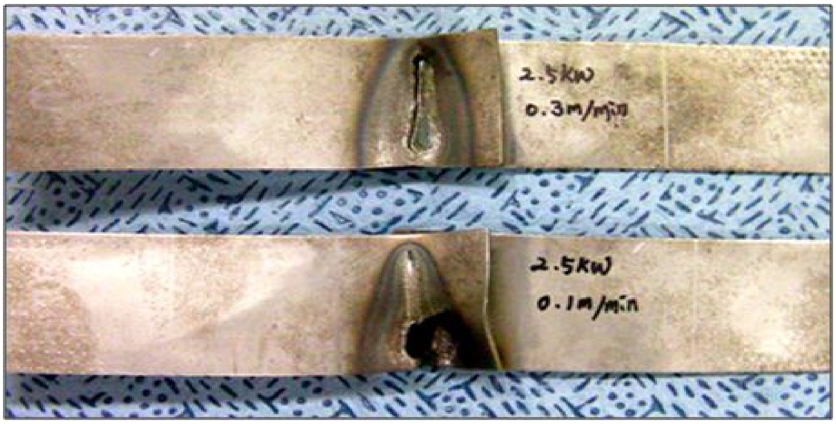
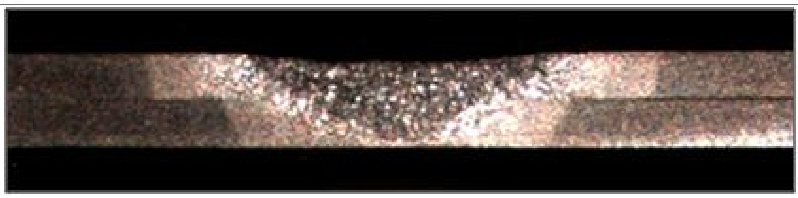
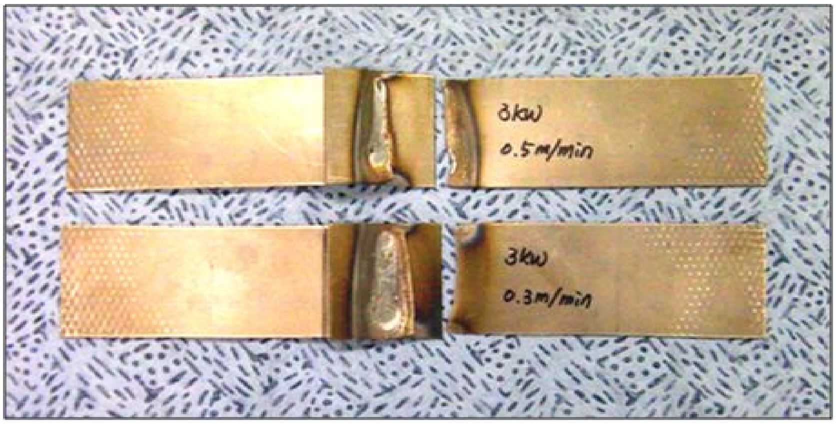
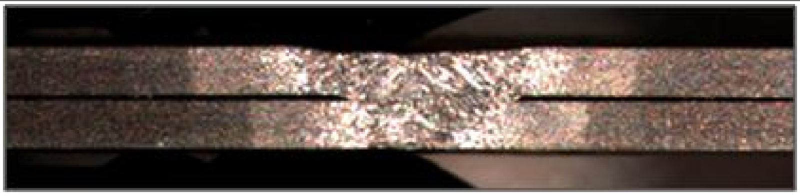
Welding Speed		Top Bead	Bottom Bead	Shear Strength (kN)
3.0KW	0.1m/min			–
	0.3m/min			18.69kN
	0.5m/min			17.69kN
	0.7m/min			13.53kN
	1.0m/min			5.20kN

Table 4.3 Laser welded specimen after Tensile-Shear Test and Cross Section

<table>
<tr><td rowspan="6">2.0KW</td><td>
</td></tr>
<tr><td>After Tensile-Shear Test</td></tr>
<tr><td></td></tr>
<tr><td>2.0KW_0.3m/min</td></tr>
<tr><td></td></tr>
<tr><td>2.0KW_0.1m/min</td></tr>
</table>

<table>
<tr><td rowspan="6">2.5KW</td><td>
</td></tr>
<tr><td>After Tensile-Shear Test</td></tr>
<tr><td></td></tr>
<tr><td>2.5KW_0.3m/min</td></tr>
<tr><td></td></tr>
<tr><td>2.5KW_0.1m/min</td></tr>
</table>

<table>
<tr><td rowspan="6">3.0KW</td><td>
</td></tr>
<tr><td>After Tensile-Shear Test</td></tr>
<tr><td></td></tr>
<tr><td>3.0KW_0.5m/min</td></tr>
<tr><td></td></tr>
<tr><td>3.0KW_0.3m/min</td></tr>
</table>

4.1.2 Experiment by each Bead-Size

In this experiment, Nd:YAG Laser Stitch Welding equipment used to condition selection 3KW grade Nd:YAG laser welding using a Laser Power, Welding Speed as a variable and, Focal Depth and +1 mm, Shielding Gas and Argon 15ℓ/min were welded to.

Weld bead surface, as well as photographs selected by the state and Spot Welding using a specimen of the same size as the 10mm, 15mm, 20mm welded tensile tests were conducted, each Nd:YAG Laser welding of the beads determines the length of Stitch was.

Optimal Laser Stitch Welding conditions are shown in Table 4.4. Fig. 4.1 of result of Nd:YAG Laser Stitch Welding of Bead-Size shows. And Laser Stitch Welded Specimen after Tensile-Shear Test of Bead-Size are shown Table 4.5.

Table 4.4 Optimal Nd:YAG Laser Stitch Welding Condition

Laser Power	Focal Depth	Welding Speed	Shielding Gas
3.0KW	+1 mm	0.3 m/min	Argon 15ℓ/min

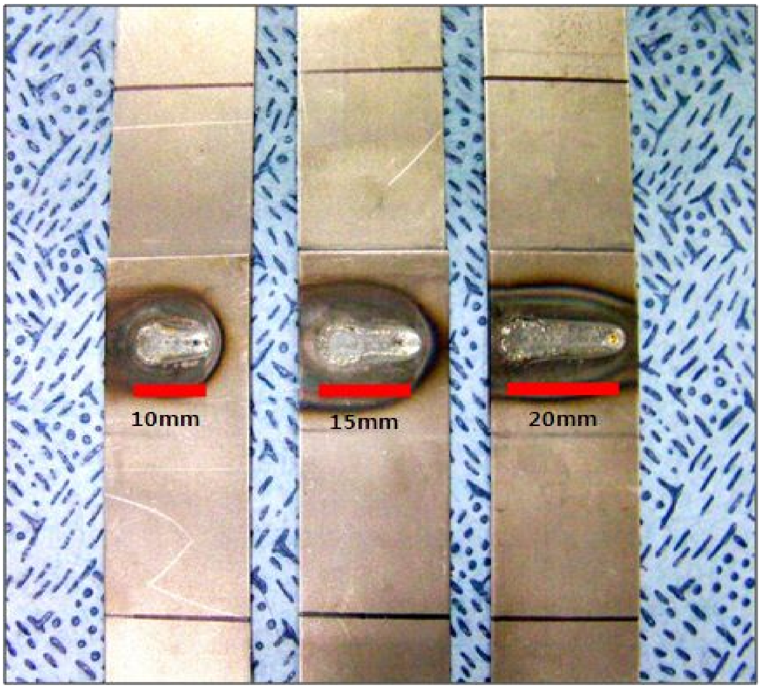
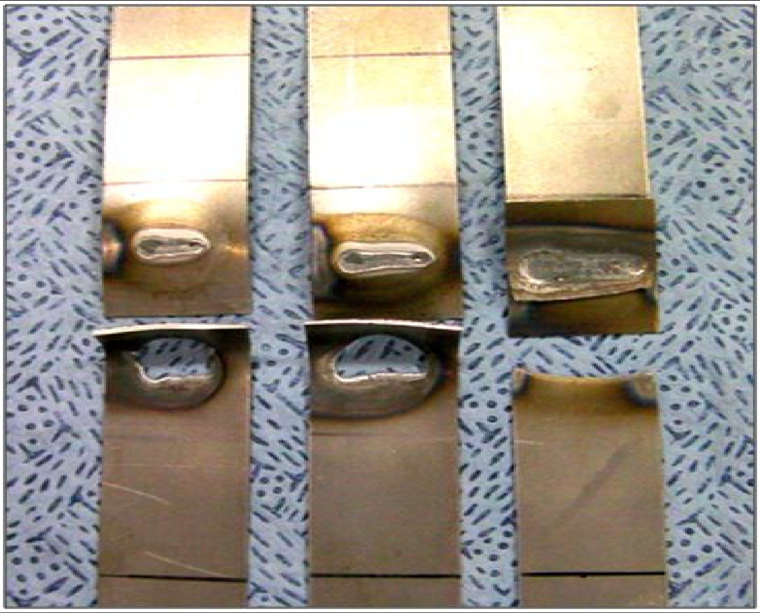
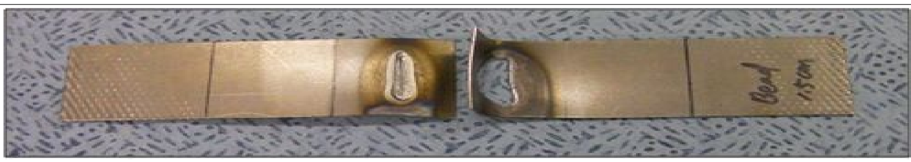


Fig. 4.1 Result of Nd:YAG Laser Stitch Welding of Bead-Size

Table 4.5 Laser Stitch Welded Specimen after Tensile-Shear Test of Bead-Size


After Tensile-Shear Test

Bead-Size 10mm

Bead-Size 15mm

Bead-Size 20mm

4.1.3 Experiment by each Pitch-Size

The pitch of Nd:YAG Laser Stitch welding department 30mm to pile up the multi spot welding specimen DP590 at 300×100×1mm sizes and produce, the spot welding department pitch of the actual automobile pitch of the spot welding to investigate.

Specimen geometry for Laser Stitch Welding shown in Fig. 4.2. Table. 4.6 of result of Laser Stitch Welded Specimen of each Pitch-Size are shown.

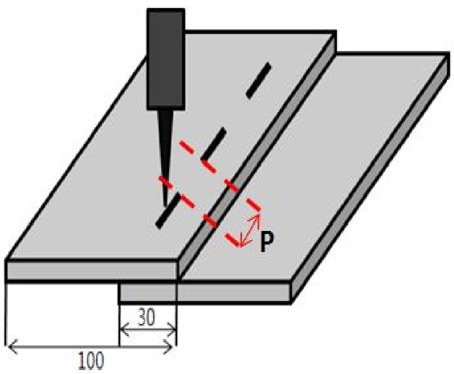
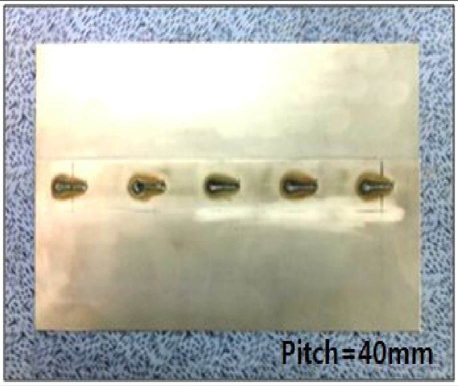
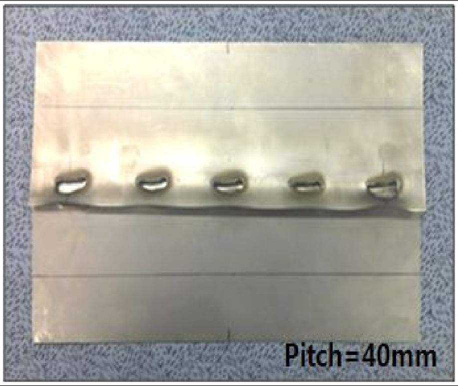
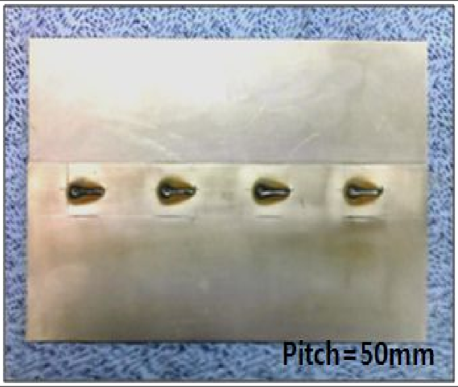
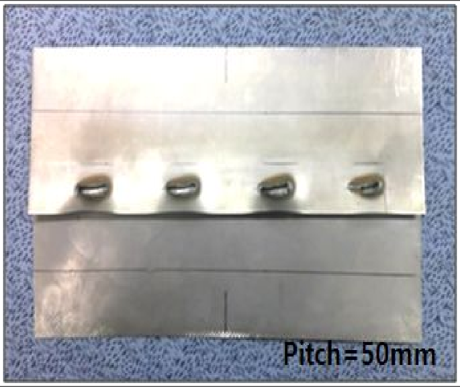
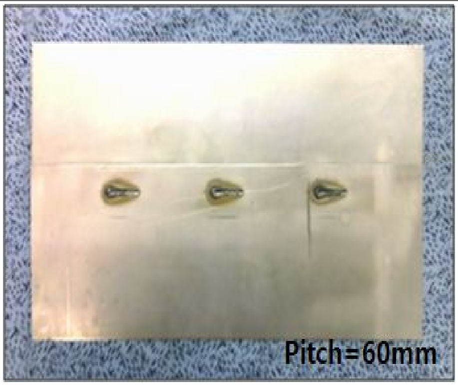
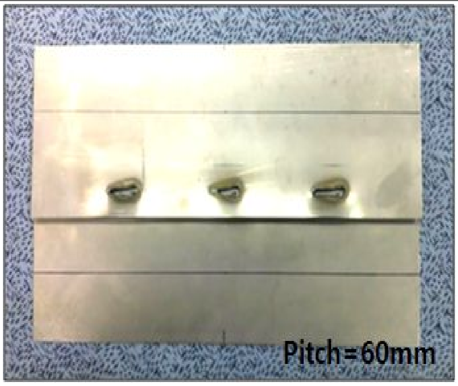


Fig. 4.2 Specimen geometry for Laser Stitch Welding
: Pitch = 40mm, 50mm, 60mm

Table. 4.6 Nd:YAG Laser Stitch Welded Specimen of each Pitch-Size

	
Pitch=40mm_Top Bead	After Tensile-Shear Test
	
Pitch=50mm_Top Bead	After Tensile-Shear Test
	
Pitch=60mm_Top Bead	After Tensile-Shear Test

4.2 Tensile-Shear Test results

4.2.1 Tensile-Shear Test of Nd:YAG Laser Welding

Prior to this experiment of DP590 Laser Stitch welding in order to identify the characteristics of the tensile strength and Table 4.2 were tested with the same conditions. Fig. 4.3, Tensile Stress-Strain curve section and wave characteristics are shown.

Nd:YAG Laser Stitch Welding Conditions for the experiment as a result of a full penetration weld defect-free output occurring conditions 3KW, welding speed can present 0.3m/min.

The tensile strength of the Nd:YAG Laser Stitch welded joints was obtained as 644Mpa and shear strength is 18.69kN which is over the tensile strength of base metal (595MPa).

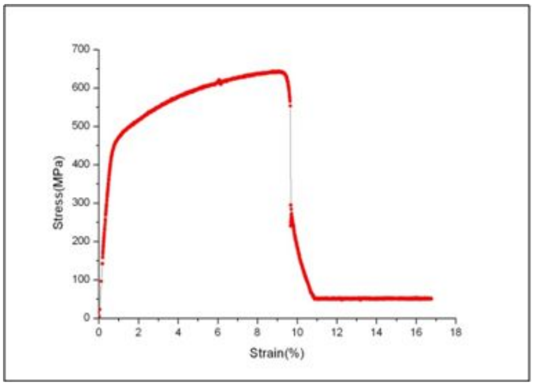
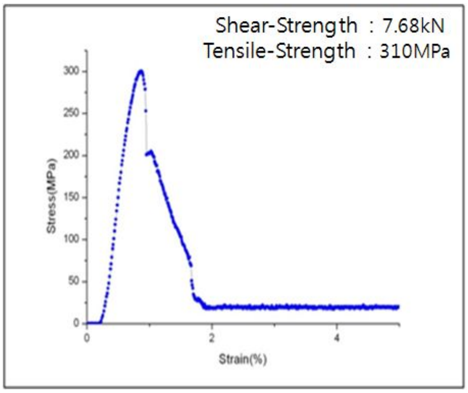
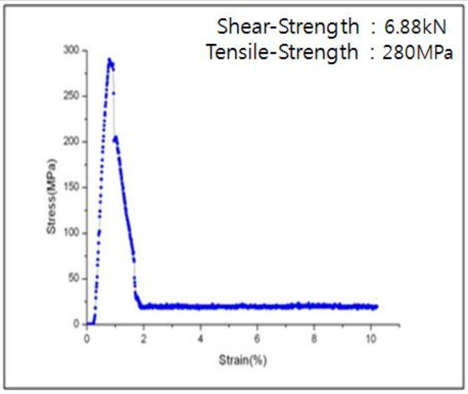


Fig. 4.3 Tensile Stress-Strain curve section and wave characteristics (3KW_0.3m/min)

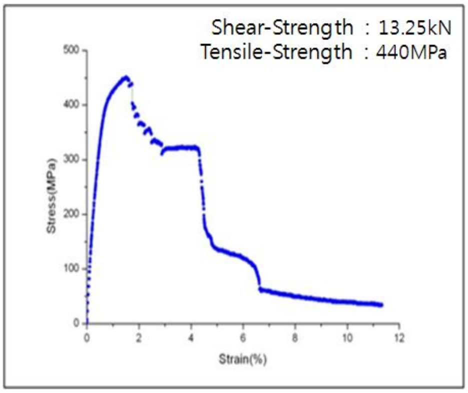
Table 4.7 Result of Tensile-Shear Test in Nd:YAG Laser Welding



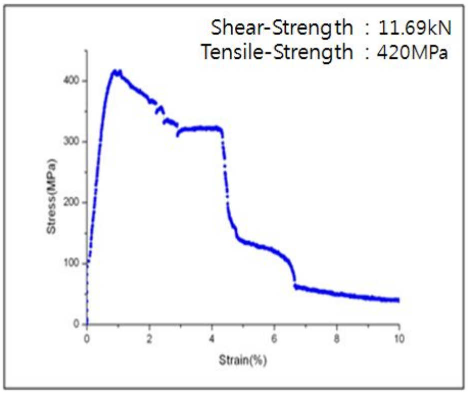
2.0KW_0.1m/min



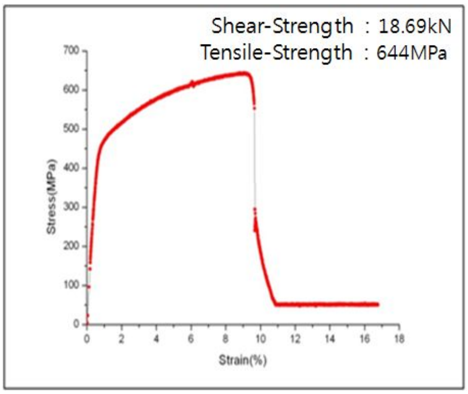
2.0KW_0.3m/min



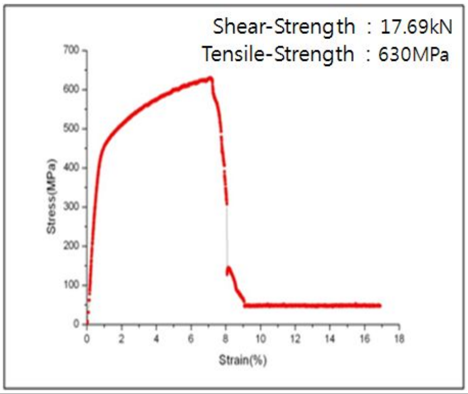
2.5KW_0.1m/min



2.5KW_0.3m/min

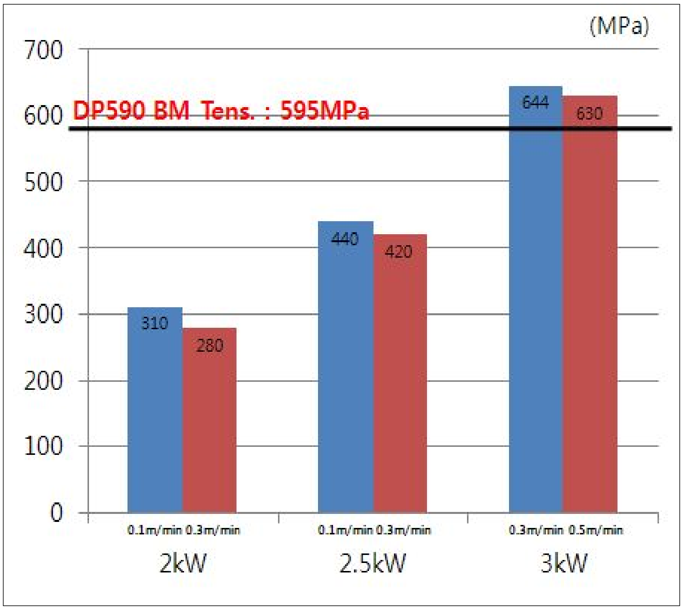


3.0KW_0.3m/min

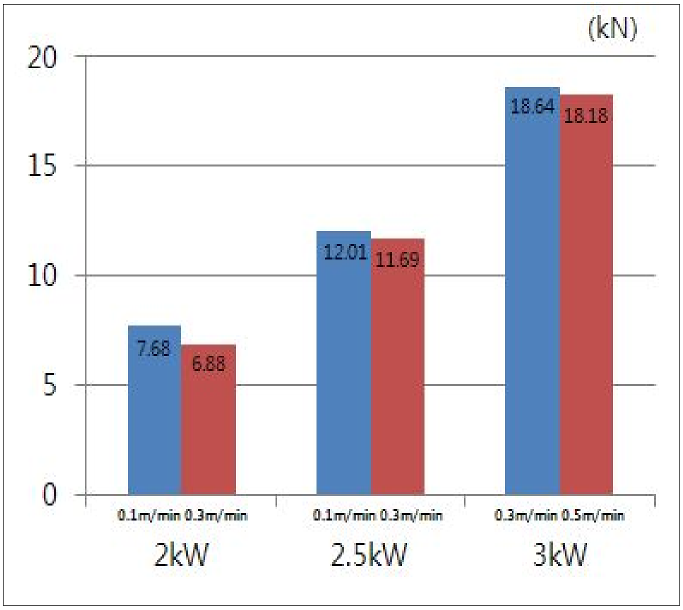


3.0KW_0.5m/min

Table 4.8 Tensile Strength and Shear Strength by each conditions



Result of Tensile-Strength by each conditions



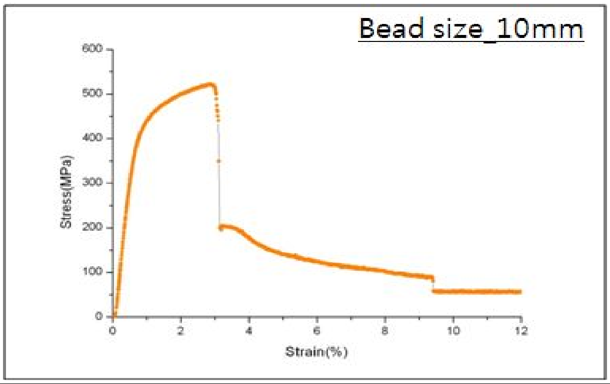
Result of Shear-Strength by each conditions

4.2.2 Tensile-Shear Test of each Bead-Size

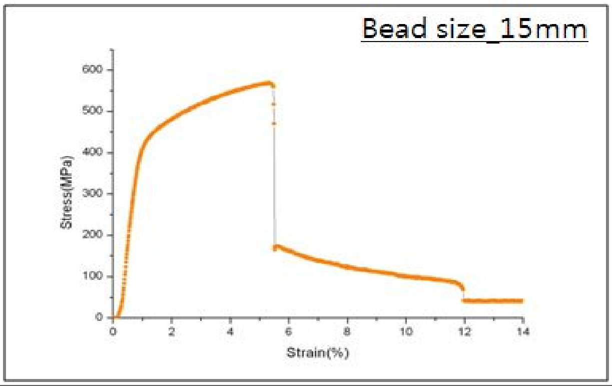
Prior to this experiment, the intensity was shown the best experimental conditions were carried out. And Spot Welding using a specimen of the same size as the 10mm, 15mm, 20mm welded tensile tests were conducted, each Nd:YAG Laser Stitch Welding of the beads determines the length of Stitch was.

Table 4.9 and Table 4.10 of the Result of Tensile Test in Nd:YAG Laser Stitch Welding and Tensile Strength and Shear Strength of each Bead-Size results.

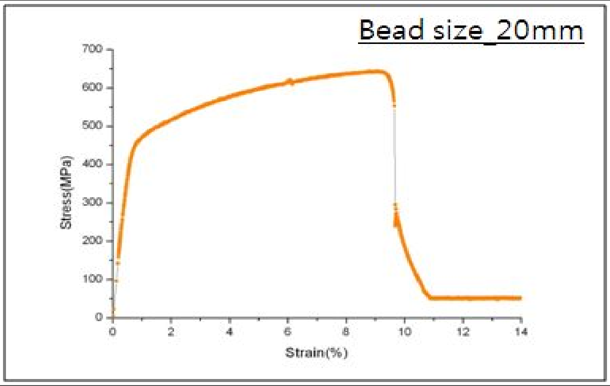
Table 4.9 Result of Tensile-Shear Test in Nd:YAG Laser Stitch Welding of Bead-Size



Bead-Size : 10mm

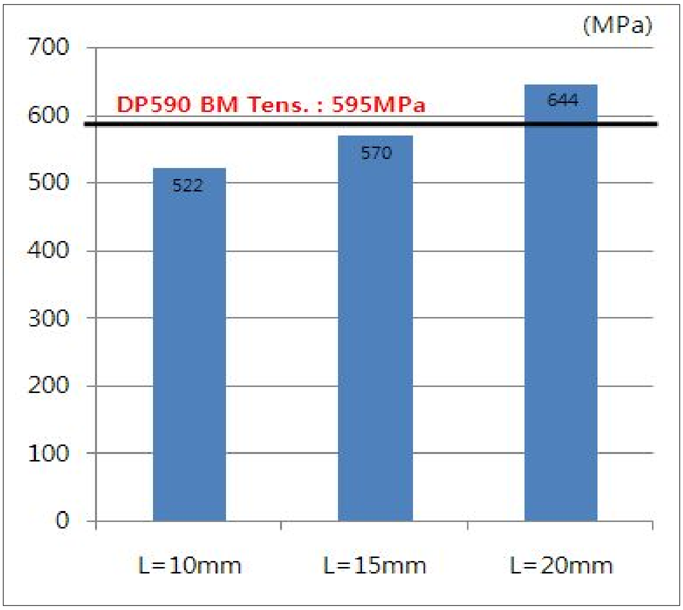


Bead-Size : 15mm

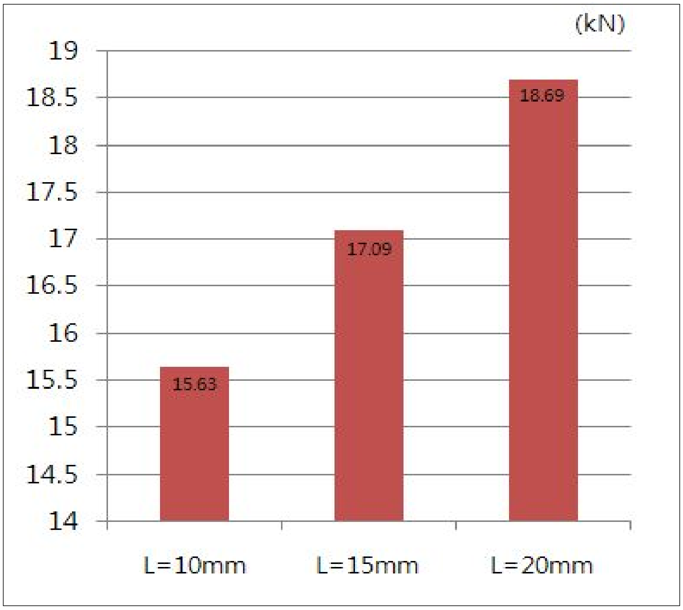


Bead-Size : 20mm

Table 4.10 Tensile Strength and Shear Strength of Bead-Size



Result of Tensile-Strength by Bead-Size



Result of Shear-Strength by Bead-Size

4.2.3 Tensile-Shear Test of each Pitch-Size

Investigates the pitch of the welding department spot welding from the actual automobile and after deciding the length of multi point welding department pitch respectively with 40mm, 50mm and 60mm, tensile load about the specimen in standard, about Nd:YAG Laser Stitch welding department pitch.

At the size which is identical with the multi spot welding specimen and Nd:YAG Laser Welding Conditions for Selected Stitch weld bead size of the weld was 20mm. And pitch for 40mm, 50mm, 60mm and a tensile test after applying, the multi spot weld tensile loading and shear strength according to the Nd:YAG laser welding of Stitch pitch were determined.

Table 4.11 and Table 4.12 of Result of Tensile Test in Nd:YAG Laser Stitch Welding of Pitch-Size and Tensile Strength and Shear Strength of Pitch-Size results.

Table 4.11 Result of Tensile-Shear Test in Nd:YAG Laser Stitch Welding of Pitch-Size

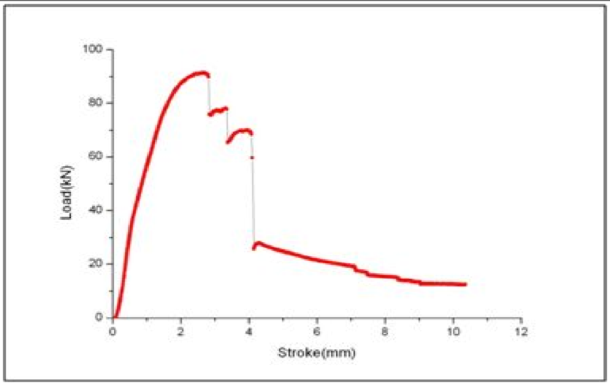
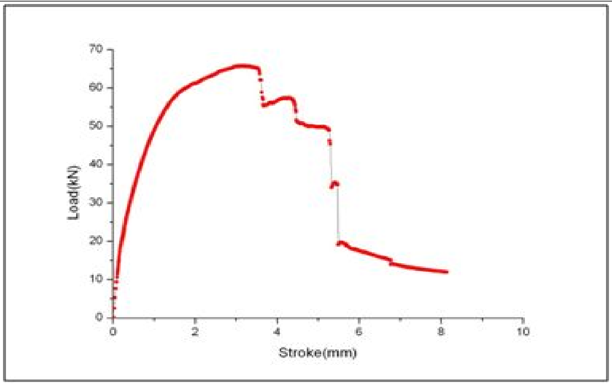
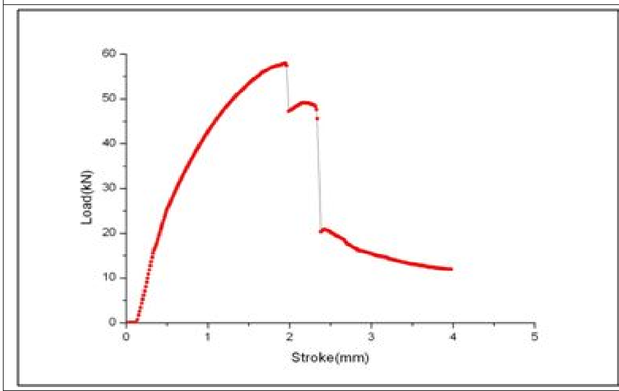
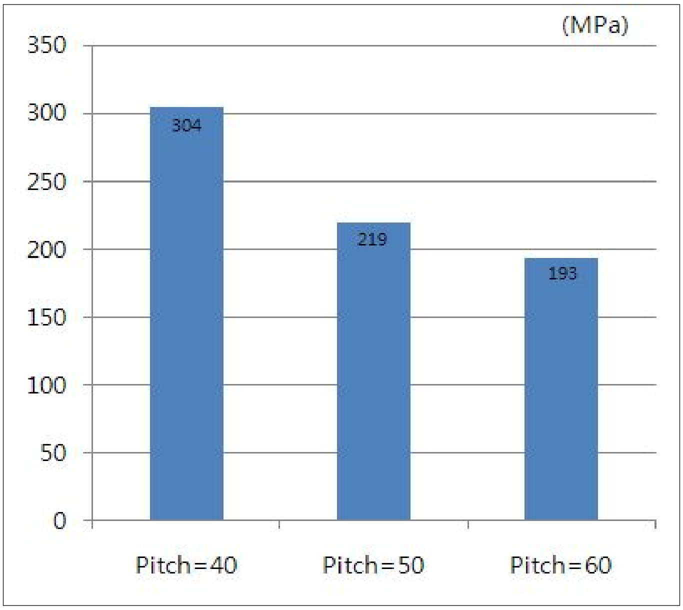
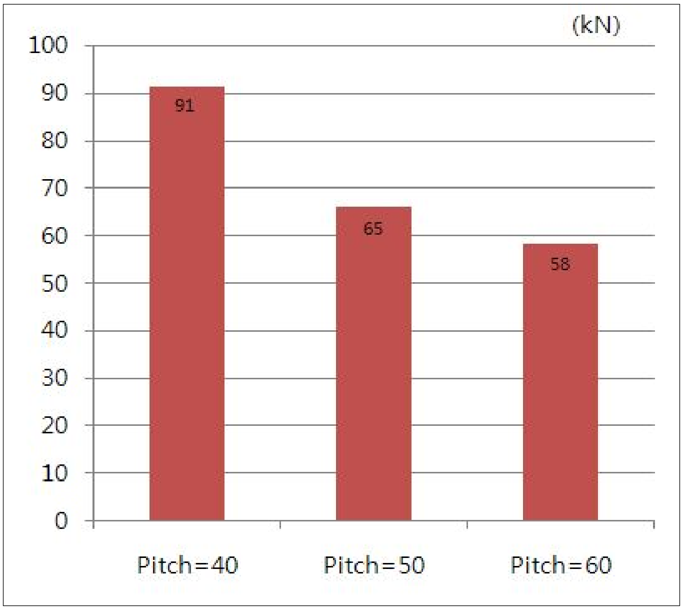

Pitch-Size : 40mm

Pitch-Size : 50mm

Pitch-Size : 60mm

Table 4.12 Tensile Strength and Shear Strength of Pitch-Size



Result of Tensile-Strength by Pitch-Size

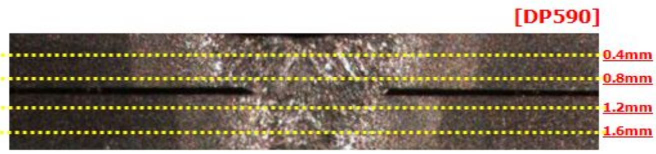


Result of Shear-Strength by Pitch-Size

4.3 Hardness Test results

The hardness distributions of joints by Nd:YAG Laser Stitch Welding is shown in Fig.4.4. The indenter employed in the Vickers test was a square-based pyramid whose opposite sides meet at the apex at an angle of 136° with load 500g applied for 10 sec.

Hardness of Laser Welded (Hardness Test) Bottom side of the specimen hardness test results from each 0.4mm, 0.8mm, 1.2mm, 1.6mm was measured as the distance, looking at the distribution of hardness with excellence and laser welding of DP590 steel Effect of hardness of the substrate during the process of the heterogeneous characteristics make of them showing a width of the weld metal hardness values. it is that almost seems to have similar characteristics.



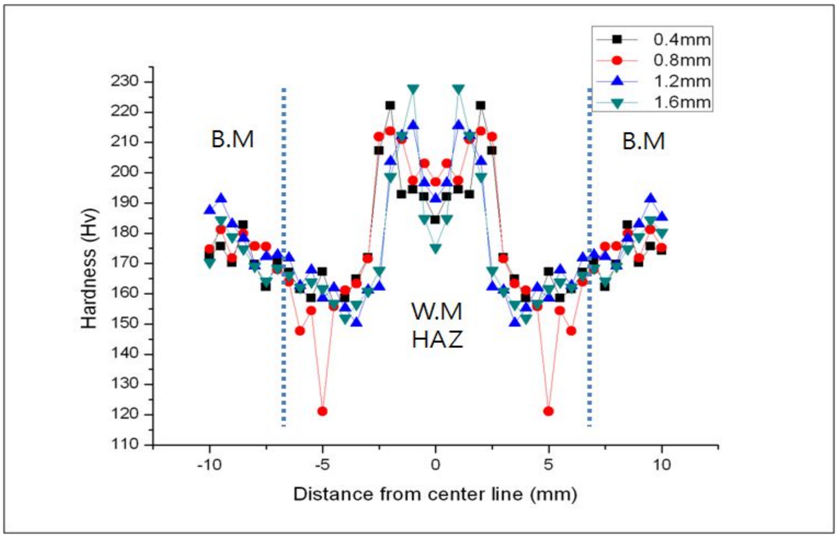
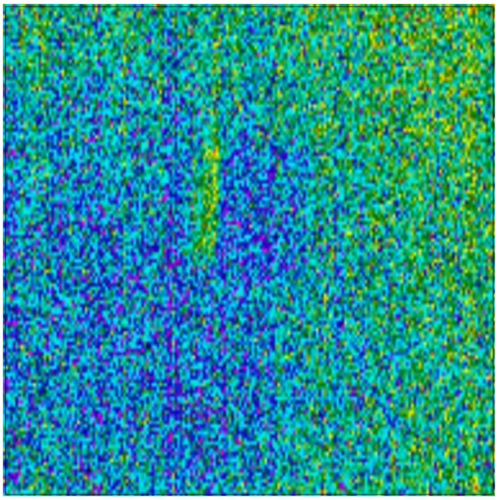


Fig. 4.4 Hardness distribution of DP590 by Nd:YAG Laser Welding

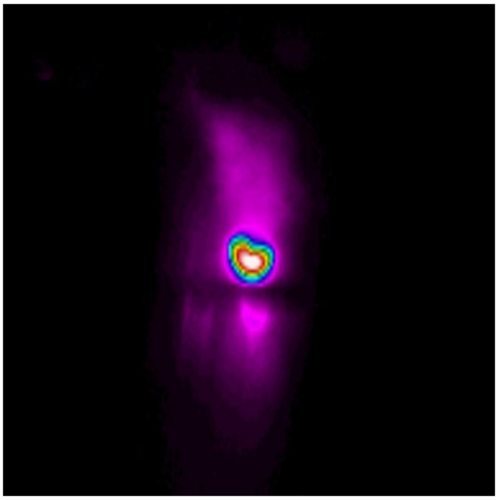
4.4 Heat Distribution Test results

The high energy density laser welding heat source in a short time by the melting, solidification process, because the heat distribution experiment using a thermal imaging camera for the short-term temperature rise of the temperature and Heat Affected Zone(HAZ) smaller than other welding methods could be seen. And high power density of laser beam within a very short time, because the welding appropriate Heat Affected Zone(HAZ) less internal stress is expected to form a welding deformation is considered to be less than.

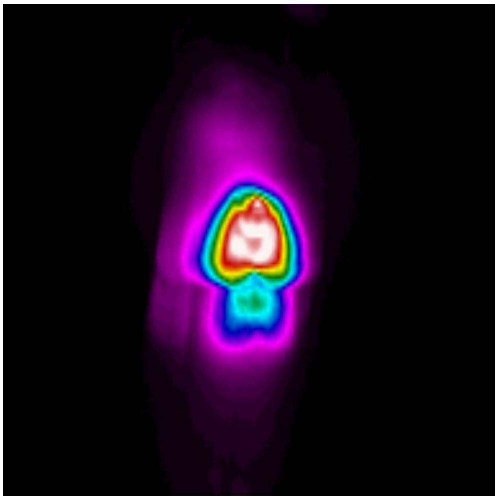
The heat distribution of Nd:YAG Laser Stitch Welded by each times is shown in Fig.4.5.



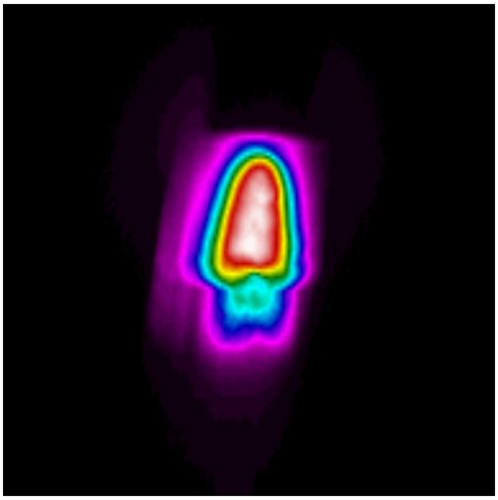
Before



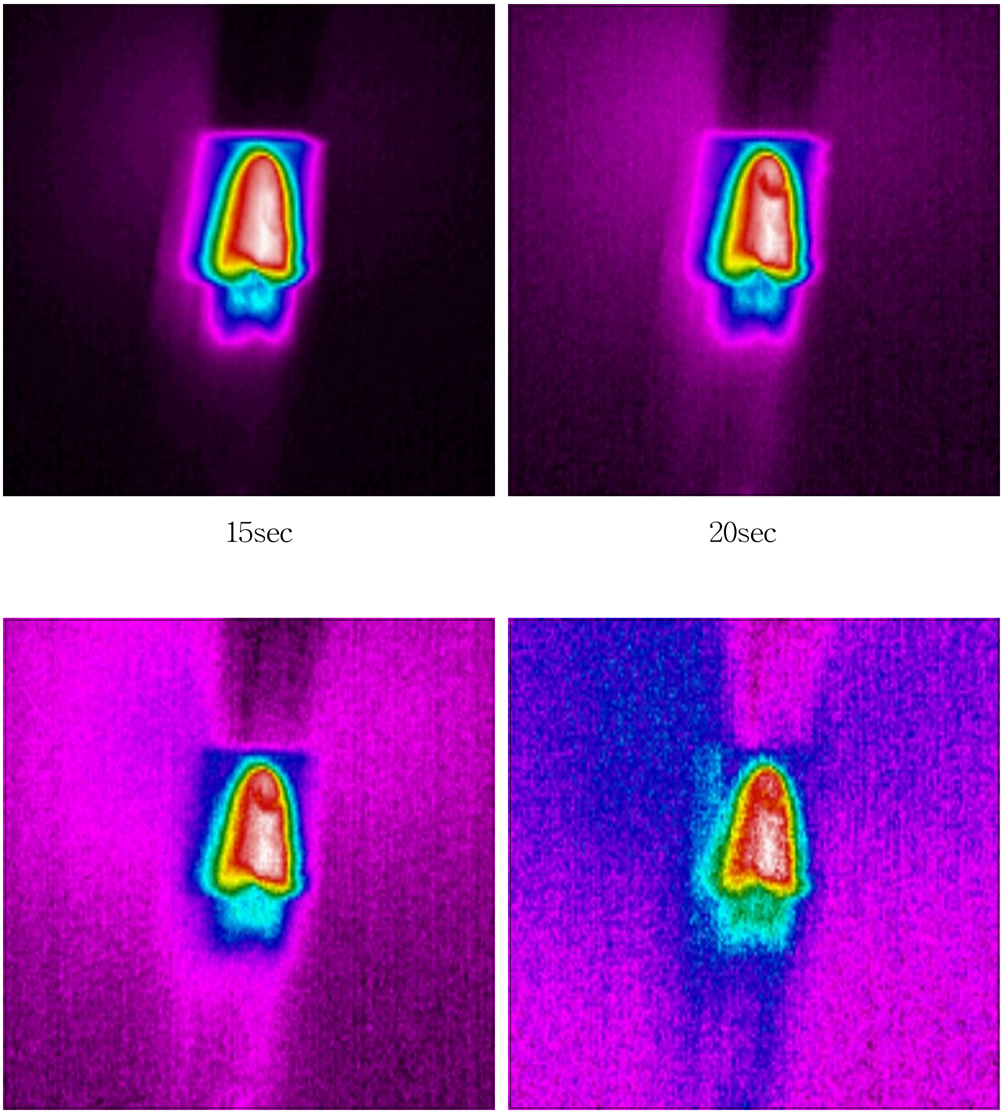
1sec



3sec



7sec



15sec 20sec

30sec 40sec

Fig. 4.5 Tendency of Heat distribution of Laser Welded by each times

Chapter 5

CONCLUSION

In this study, high-quality lasers for welding car bodies Laser Stitch Welding process to review the application of Laser Stitch welding were reviewed to evaluate the mechanical properties. High Strength Steel (AHSS_DP590) Nd: YAG Laser Welded Lap Joint by Laser Stitch Welding Weldability study results, the following conclusions could be drawn.

From this study conclusions are made as follows :

► Laser Stitch Welding Conditions for the experiment as a result of a full penetration weld defect-free output occurring conditions 3KW, welding speed can be present 0.3m/min, laser output can be increased the higher the laser was found that welding speed.

► Optimum conditions for welding in the case of tensile test specimen fracture in base metal tensile strength values were 644MPa, the shear strength values were 18.69kN than 595MPa high tensile strength, shear strength values were obtained.

- ► On the basis of optimum conditions for weld bead characteristics Size 10mm, 15mm, 20mm length of the split bead experiments, the wider the tensile shear strength and tensile test came even greater value and length of 20mm from the bead fracture was found. Size of each bead, and at regular bead size, the tensile shear strength values were extracted.

- ► Each of the pitch of Laser Stitch Welding 40mm, 50mm, 60mm, was chosen as.
  *(Spot welding gap by Pitch: 1t per spacing of 18mm or more)

- ► Hardness of Laser Welded (Hardness Test) Bottom side of the specimen hardness test results from each 0.4mm, 0.8mm, 1.2mm, 1.6mm was measured as the distance, looking at the distribution of hardness with excellence and laser welding of DP590 steel Effect of hardness of the substrate during the process of the heterogeneous characteristics make of them showing a width of the weld metal hardness values. it is that almost seems to have similar characteristics.

- ► The high energy density laser welding heat source in a short time by the melting, solidification process, because the heat distribution experiment using a thermal imaging camera for the short-term temperature rise of the temperature and Heat Affected Zone(HAZ) smaller than other welding methods could be seen. And high power density of laser beam within a very short time, because the welding appropriate Heat Affected Zone(HAZ) less internal stress is expected to form a welding deformation is considered to be less than.

- ► Nd:YAG Laser Stitch Welding available conventional resistance spot welding area more than 50% of the available space by reducing car weight and fuel efficiency improvements, cost savings may lead to such effects.

- ► These results as, Nd:YAG Laser Stitch welding process the initial installation cost of an expensive downside, despite the welding speed is fast, the weldability is very good, and the welding process also can simplify a productive in terms of a very large potential for improvements can be considered.

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논문제목	한글 : 고장력강판 (AHSS_590MPa)의 Nd:YAG Laser Stitch 용접에 관한 연구 영어 : A Study on the Weldability of AHSS (Advance High Strength Steel) by Nd:YAG Laser Stitch Welding				

본인이 저작한 위의 저작물에 대하여 다음과 같은 조건아래 조선대학교가 저작물을 이용할 수 있도록 허락하고 동의합니다.

\- 다 음 -

1. 저작물의 DB구축 및 인터넷을 포함한 정보통신망에의 공개를 위한 저작물의 복제, 기억장치에의 저장, 전송 등을 허락함
2. 위의 목적을 위하여 필요한 범위 내에서의 편집・형식상의 변경을 허락함. 다만, 저작물의 내용변경은 금지함.
3. 배포・전송된 저작물의 영리적 목적을 위한 복제, 저장, 전송 등은 금지함.
4. 저작물에 대한 이용기간은 5년으로 하고, 기간종료 3개월 이내에 별도의 의사 표시가 없을 경우에는 저작물의 이용기간을 계속 연장함.
5. 해당 저작물의 저작권을 타인에게 양도하거나 또는 출판을 허락을 하였을 경우에는 1개월 이내에 대학에 이를 통보함.
6. 조선대학교는 저작물의 이용허락 이후 해당 저작물로 인하여 발생하는 타인에 의한 권리 침해에 대하여 일체의 법적 책임을 지지 않음
7. 소속대학의 협정기관에 저작물의 제공 및 인터넷 등 정보통신망을 이용한 저작물의 전송・출력을 허락함.

동의여부 : 동의(O) 반대( )

2011 년 8 월

저작자 : 김 두 송 (서명 또는 인)

조선대학교 총장 귀하