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February 2013 Master's Thesis

Mechanical Characteristics on Welded Joints of Automative Cowl by Nd:YAG Laser Stitch Welding

Graduate School of Chosun University

Department of Naval Architecture and Ocean Engineering

Hyeong-il Kim

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February 25, 2013

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CONTENTS

List of Tables V
List of Figures VI
AbstractVIII
Chapter 1. Introduction
1 . 1 Research Background and Purpose1
1 . 2 Recent Welding Tchnique Tend for Atomative 2
1 . 3 Application of Laser Stitch Welding to Automative
Cowl4
Chapter 2. Theoretical Background
2 . 1 Spot Welding6
2.1.1 Principles of Spot Welding6
2.1.2 Welding Parameters of Spot Welding7
2.1.3 Characteristics of Spot Welding10
2 . 2 Nd:YAG Laser Welding10
2.2.1 Principles of Laser10
2.2.2 Nd:YAG Laser12
2.2.3 Parameters of Nd:YAG Laser Welding14
2.2.4 Characteristics of Nd:YAG Laser Welding 14

2.3 Laser Stitch Welding15
2 . 4 Characteristics of Objective Materials16
2.4.1 Objective Material ······16
2.4.2 Orthography of Products17
2.4.3 Cold Rolled Steel ······20
2.4.4 Galvannealed Steel21
Chapter 3. Experiment Method of Spot and Laser
Stitch Welding Process
3 . 1 Details of Spot and Laser Stitch Welding
System23
3.1.1 Spot Welding Equipment and Experimental Setup 23
3.1.2 Nd:YAG Laser Stitch Welding Equipment and
Experimental Setup24
3 . 2 Objective Material26
3 . 3 Experimental Procedure28
3.3.1 Spot Welding Condition28
3.3.2 Laser Stitch Welding Condition28
3.3.3 Conditions of Laser Stitch Welding to Compared
with Spot Welding29
3 . 4 Evaluation of Mechanical and Metallurgical
Characteristics31

3.4.1 Shear Test31
3.4.2 Hardness Test32
3.4.3 Microstructure Analysis34
3.4.4 Temperature Distribution Analysis35
Chapter 4. Mechanical and Metallurgical
Characteristics of Spot and Laser Stitch Welded Joints
4 . 1 Optimization of Spot and Laser Stitch Welding $\cdot\cdot$ 37
4.1.1 Experiment by Spot Welding37
4.1.2 Experiment by Laser Stitch Welding40
4.1.3 Comparison of Bead Profiles of Spot Welding and
Laser Stitch Welding46
4 . 2 Shear Test Results47
4.2.1 Shear Srength of Spot Welded Joints47
4.2.2 Shear Strength of Laser Stitch Welded Joints 52
4.2.3 Comparison of Shear Strength of Spot and Laser
Stitch Welded Joints61
4 . 3 Hardness Test Results63
4 . 4 Measured Temperature Distribution Results 66
4 . 5 Microstructure Analysis68
4.5.1 Microstructure of Spot Welding68
4.5.2 Microstructure of Laser Stitch Welding71

Chapter 5.	Conclusion	74
Reference	•••••	76

List of Tables

Table 2.1	Chemical compositions in SGACC 60/60 and SGARC 340 16
Table 2.2	Mechanical properties of SGACC 60/60 and SGARC 340 ·· 16
Table 2.3	Material symbol of SGACC 60/60 and SGARC 340 17
Table 2.4	Application parts of SGACC 60/60 and SGARC 34019
Table 3.1	Specifications of spot welding equipment24
Table 3.2	Specification of Nd:YAG laser welding equipment25
Table 3.3	Chemical compositions in SGACC 60/60 and SGARC 340 27
Table 3.4	Mechanical properties of SGACC 60/60 and SGARC 340 - 27
Table 3.5	Welding parameters of spot welding28
Table 3.6	Welding parameters of laser stitch welding29
Table 3.7	Dimension of tensile test specimen32
Table 3.8	Micro vickers hardness tester 33
Table 4.1	Conditions of BOP test
Table 4.2	Conditions of spot welding39
Table 4.3	Conditions of laser stitch welding40
Table 4.4	Bead appearance of spot welded joints46
Table 4.5	Bead appearance of laser stitch welded joints for various
	welding parameters46
Table 4.6	Shear strength of BOP test50
Table 4.7	Shear strength of spot welded joints50
Table 4.8	Shear strength of laser stitch welded joints 55
Table 4.9	Fractured specimen of optimized spot welded joints after
	shear test62
Table 4.10	Fractured specimen of laser stitch welded joints after
	shear test62

List of Figures

Fig.	1.1	Bonding technique of automative	2
Fig.	1.2	Comparison of welding time of spot and laser welding	3
Fig.	1.3	Shape of cowl	4
Fig.	1.4	Location of cowl	5
Fig.	2.1	Principles of spot welding	7
Fig.	2.2	Schematic of Nd:YAG laser1	2
Fig.	2.3	Applications to SGACC 60/60 and SGARC 340 industry 1	8
Fig.	2.4	Manufacturing process of cold rolled sheet2	1
Fig.	3.1	Spot welding equipment2	3
Fig.	3.2	Nd:YAG laser equipment2	4
Fig.	3.3	Laser welding system2	6
Fig.	3.4	Schematic of specimen dimension 2	7
Fig.	3.5	Experimental setup for laser stitch welding2	9
Fig.	3.6	Schematic of spot welding3	0
Fig.	3.7	Schematic of laser stitch welding3	0
Fig.	3.8	Process of shear test3	1
Fig.	3.9	Micro vickers hardness tester3	3
Fig.	3.10	Hardness measurement points of welded specimen3	3
Fig.	3.11	Optical microscope3	4
Fig.	3.12	Thermal CAM_P25 ······3	5
Fig.	3.13	Specifications of thermal CAM_P253	6
Fig.	4.1	Comparison of shear strength4	8
Fig.	4.2	Shear strength of welded joints in optimized welding	
		conditions4	9
Fig.	4.3	Shear strength of welded joints with welding speed(bead	

	length 10mm)53
Fig. 4.4	Shear strength of welded joints with welding speed(bead
	length 20mm)53
Fig. 4.5	Shear strength of welded joints with welding speed(bead
	length 30mm)54
Fig. 4.6	Shear strength of welded joints in optimized welding
	conditions54
Fig. 4.7	Shear strength of welded joints for various pitch61
Fig. 4.8	Hardness distribution of spot welded joints64
Fig. 4.9	Hardness distribution of laser stitch welded joints 64
Fig. 4.10	Comparison of hardness distribution of spot and laser stitch
	welded joints 65
Fig. 4.11	Temperature distribution of spot welded joints66
Fig. 4.12	Temperature distribution of laser stitch welded joints 67
Fig. 4.13	Comparison of temperature distribution of spot and laser
	stitch welded joints67
Fig. 4.14	Cross section of welded joints68
Fig. 4.15	Microstructures of spot welded joints69
Fig. 4.16	SEM image of fractured surface of spot welded joints after
	shear70
Fig. 4.17	SEM image of spot welded joints70
Fig. 4.18	Cross section of laser stitch welded joints71
Fig. 4.19	Microstructures of laser stitch welded joints72
Fig. 4.20	SEM image of fractured surface of laser stitch welded joints
	after shear ····································

ABSTRACT

레이저 스티치 용접을 적용한 자동차 카울 용접부의 기계적 특성

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최근 자동차업계는 연비향상, 환경오염 및 지구 온난화 등에 대비하여 이산화탄소의 배출이 적고 연비가 대폭 향상된 하이브리드 자동차, 전기 자동차등 친환경 자동차 개발에 초점을 맞추고 있을 뿐만 아니라 자동차에 적용중인 강판의 재질을 고장력강으로 대체하여 자동차의 경량화 및 연비향상에 이바지하고 운전자의 안전을 확보하는데 일조하고 있다.

또한 경량화, 생산성 향상 및 고품질의 자동차를 생산하기 위한 방법으로 점용접 대신 레이저 스티치 용접을 자동차에 적용한 연구가 활발히 진행되고 있다. 기존의 점용접은 Filler material이 불필요하고 비숙련공이 기계를 조작할 수 있는 반면 용접 후 용접부에 압흔이 생성되며 전극 직경에 따라 Flange의 면적이 증가하고 이에 따른 자동차의 중량이 증가하게 되며 또한 점용접은 복잡한 형상의 부품에 적용하기 힘들다는 단점을 가지고 있다.

이에 따라 카울에 적용되는 점용접의 단점을 보완하고 생산성향상 및 고품질의 제품을 생산하기 위해 레이저 스티치 용접을 적용한 연구를 진행하고

있다. 레이저 스티치 용접은 용접부의 강도를 향상 시키고 용접부의 면적을 최소화하여 자동차의 중량을 감소시키고 용접변형을 최소화하여 고품질의 제 품생산을 생산할 수 있으며 레이저 용접에 비해 전력소모가 적고 복잡한 형 상에도 적용 가능하다. 또한 점용접에 비해 용접속도가 빠르므로 생산성 향 상시킬 수 있으며 한 대의 용접기로 상당한 부분의 용접을 할 수 있으므로 공장라인을 간소화 할 수 있는 장점이 있다.

본 연구에서는 자동차 카울에 적용되는 고강도강판(HSS:high strength steel) SGACC 60/60와 SGARC 340 판재에 점용접과 레이저 스티치용접을 실시하여 각각의 최적 용접조건을 도출하여 레이저 스티치 용접의 비드길이, 피치간격 변화에 따른 기계적 특성 및 금속학적 특성을 분석하여 점용접과 비교/평가하여 레이저 스티치 용접의 산업분야 적용 가능성을 고찰하고자 하였다.

Chapter 1

Introduction

1.1 Research Background and Purpose

Environmental regulations of CO_2 , improve of fuel efficiency and crash safety regulations is strengthened in the automotive industry. Therefore each country focus on eco-friendly car, weight lightening, high intensity and performance to reduce waste of fuel.

Weight lightening of car contribute to reduce emitting harmful gas. Nonferrous metal(AI, Mg, specialty reinforcement plastic) is applied in various industry. But many problems occure aspect of cost, weldability and strength. Respond to those things, automobile company apply to laser welding instead of spot welding on the HSS(high strength steel). Laser welding complement drawback of spot welding and has lots of advantages like high bond strength, few deformation. technical development that is applied by laser welding is progressing favorably to retain the safety of car.

Spot welding make indentations after welding and Flange depend on electrode diameter. Also it's hard to apply complicated parts. Laser welding produce good quality products and productivity is high than spot welding but first cost of installation is high. Therefore laser stitch welding is applied to complement fault of spot welding and laser stitch welding. It already applied in Europe of car and applications will be increased in the world gradually.

Laser stitch welding can be welded above a long distance fast and improve productivities. In addition it is possible to simpleness of working process and improvement of bond strength and mileage, weigh lightening of car and reduction of cost of production. Consequently it overcome economical and

technical matters. Also domestic auto company has to apply to laser stitch welding and study its weldability and another welding. (If the laser stitch welding apply to cars, area of flange decrease over 50%.)

In this study, SGACC 60/60 and SGARC 340 applied cowl(HSS:high strength steel) were jointed and optimized condition was obtained. Characteristics of mechanical and metallurgical were studied about bead length and pitch in spot welding and laser stitch welding.

1.2 Recent Welding Tchnique Tend for Atomative

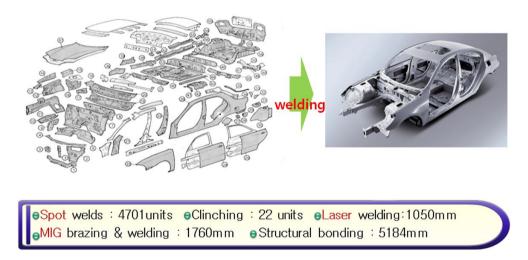


Fig. 1.1 Bonding technique of automative

The newest technique is developing to study high strength, light weight and improvement of productivity steadily. Therefore technique of 3D-laser welding is coming up industry of automobile to overcome drawback of spot welding.

Weight lightening of car is important during the oil shock of two times was overcame. AHSS(Advanced high strength steel) is studying to reduce the weight of car and using the laser welding is the best to decrease area of flange.

Therefore welding technique is changing spot welding to laser welding because it produces high quality goods and productivity is improved. Laser welding is applied to producing complicated parts of car.

Advanced country applied Nd:YAG laser welding in parts of auto and productivity improved to 45% compare to spot welding. But applying the laser welding is different due to high cost of installation.

3D laser welding is faster than spot welding to quintuple and domestic auto company has to develop the laser welding and a newest technique. Also it applied limited parts of car and a lasted technique is developed to weight lightening.

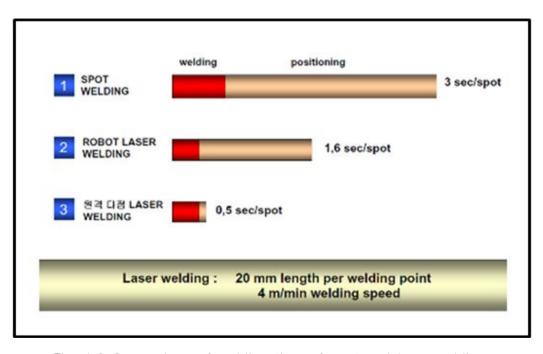


Fig. 1.2 Comparison of welding time of spot and laser welding

1.3 Application of Laser Stitch Welding to Automative Cowl

The cowl is to prevent water entering the engine room, ventilation ducts and protected from the external environment. Also wiper motor is positioned.

In this study, automotive cowl for high-strength steel(HSS) of SGACC 60/60 and SGARC 340 was fabricated by laser stitch welding. In order to improve weldability and productivity, the analysis of the mechanical properties and metallurgical characteristics of laser stitch welded joints was carried out to establish the reliability of laser stitch welding.

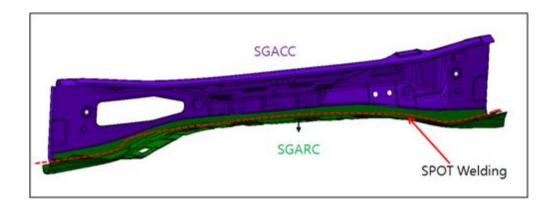


Fig. 1.3 Shape of cowl

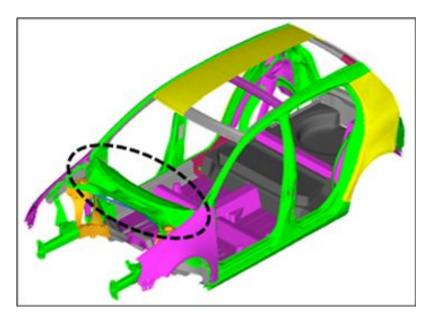


Fig 1.4 Location of cowl

Chapter 2

Theoretical Background

2.1 Spot Welding

2.1.1 Principles of Spot Welding

Resistance welding processes are pressure welding processes in which heavy current is passed for short time through the area of interface of metals to be joined. These processes differ from other welding processes in the respect that no fluxes are used, and filler metal rarely used. All resistance welding operations are automatic and, therefore, all process variables are preset and maintained constant. Heat is generated in localized area which is enough to heat the metal to sufficient temperature, so that the parts can be joined with the application of pressure. Pressure is applied through the electrodes.

The heat generated during resistance welding is given by following expression:

 $H = I^2 R T$

Where, H is heat generated

I is current in amperes

R is resistance of area being welded

T is time for the flow of current.

The process employs currents of the order of few KA, voltages range from 2 to 12 volts and times vary from few ms to few seconds. Force is normally applied before, during and after the flow of current to avoid arcing between the surfaces and to forge the weld metal during post heating. The necessary pressure shall vary from 30 to 60 N/mm² depending upon material to be welded and other welding conditions. For good quality welds these parameters may be properly selected which shall depend mainly on material of components, their thicknesses, type and size of electrodes.

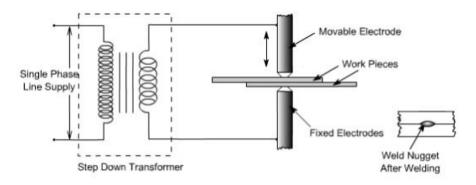


Fig. 2.1 Principles of spot welding

2.1.2 Welding Parameters of Spot Welding

1) Current

The weld current is the current in the welding circuit during the making of a weld. The amount of weld current is controlled by two things; first, the setting of the transformer tap switch determines the maximum amount of weld current available; second the percent of current control determines the percent of the available current to be used for making the weld. Low percent current settings are not normally recommended as this may impair the quality

of the weld. Adjust the tap switch so that proper welding current can be obtained with the percent current set between seventy and ninety percent.

The weld current should be kept as low as possible. When determining the current to be used, the current is gradually increased until weld spatter occurs between the metal sheets. This indicates that the correct weld current has been reached.

2) Welding time

Weld time is the time during which welding current is applied to the metal sheets. The weld time is measured and adjusted in cycles of line voltage as are all timing functions. One cycle is 1/50 of a second in a 50 Hz power system. (When the weld time is taken from American literature, the number of cycles has to be reduced due to the higher frequency (60Hz) that is used in the USA.)

As the weld time is, more or less, related to what is required for the weld spot, it is difficult to give an exact value of the optimum weld time. For instance:

- Weld time should be as short as possible.
- The weld current should give the best weld quality as possible.
- The weld parameters should be chosen to give as little wearing of the electrodes as possible. (Often this means a short weld time.)
- The weld time shall cause the nugget diameter to be big when welding thick sheets.
- The weld time might have to be adjusted to fit the welding equipment in case it does not fulfil the requirements for the weld current and the electrode force.
- The weld time shall cause the indentation due to the electrode to

be as small as possible.

 The weld time shall be adjusted to welding with automatic tip-dressing, where the size of the electrode contact surface can be kept at a constant value. (This means a shorter welding time.)

When welding sheets with a thickness greater than 2 mm it might be appropriate to divide the weld time into a number of impulses to avoid the heat energy to increase. This method will give good-looking spot welds but the strength of the weld might be poor.

By multiplying the thickness of the sheet by ten, a good target value for the weld time can be reached. When welding two sheets with the thickness 1 mm each, an appropriate weld time is 10 periods (50Hz).

3) Electrode force

The purpose of the electrode force is to squeeze the metal sheets to be joined together. This requires a large electrode force because else the weld quality will not be good enough. However, the force must not be to large as it might cause other problems. When the electrode force is increased the heat energy will decrease. This means that the higher electrode force requires a higher weld current. When weld current becomes to high spatter will occur between electrodes and sheets. This will cause the electrodes to get stuck to the sheet.

An adequate target value for the electrode force is 90 N per mm². One problem, though, is that the size of the contact surface will increase during welding. To keep the same conditions during the hole welding process, the electrode force needs to be gradually increased. As it is rather difficult to change the electrode force in the same rate as the electrodes are "mushroomed", usually an average value is chosen.

2.1.3 Characteristics of Spot Welding

- 1) Advantages of Spot Welding
- High productivity.
- · Without filler material.
- · Any person can do the spot welding.
- Suitable for mass production.
- 2) Disadvantages of Spot Welding
- High current is required.
- Difficult to apply to the complex geometry of the parts.
- Creation of indentation
- · Weight of the car is increased due to flange.
- · Harmful gases during welding.
- · Constrained to body design and automation.
- · Plated steel and laminated steel sheet weldability of degradation

2.2 Nd:YAG Laser Welding

2.2.1 Principles of Laser

A laser is a device that emits light (electromagnetic radiation) through a process of optical amplification based on the stimulated emission of photons. The term "laser" originated as an acronym for Light Amplification by Stimulated Emission of Radiation. The emitted laser light is notable for its

high degree of spatial and temporal coherence.

Spatial coherence is typically expressed through the output being a narrow beam which is diffraction-limited, often a so-called "pencil beam." Laser beams can be focused to very tiny spots, achieving a very high irradiance, or they can be launched into beams of very low divergence in order to concentrate their power at a large distance.

Temporal (or longitudinal) coherence implies a polarized wave at a single frequency whose phase is correlated over a relatively large distance (the coherence length) along the beam. A beam produced by a thermal or other incoherent light source has an instantaneous amplitude and phase which vary randomly with respect to time and position, and thus a very short coherence length.

Most so-called "single wavelength" lasers actually produce radiation in several modes having slightly different frequencies (wavelengths), often not in sinale polarization. And although temporal coherence implies monochromaticity, there are even lasers that emit a broad spectrum of light, or emit different wavelengths of light simultaneously. There are some lasers which are not single spatial mode and consequently their light beams diverge more than required by the diffraction limit. However all such devices are classified as "lasers" based on their method of producing that light: stimulated emission. Lasers are employed in applications where light of the required spatial or temporal coherence could not be produced using simpler technologies.

2.2.2 Nd:YAG Laser

An essential part of the structure of the laser is actually required to generate the laser light Fig. 2.2 can be represented simply as shown in actual laser that generates the laser light as part of the things that is needed to control the characteristics of the light output, system stability, and are at least as important as the rest, except for the part needed to generate light allow the use of stable.

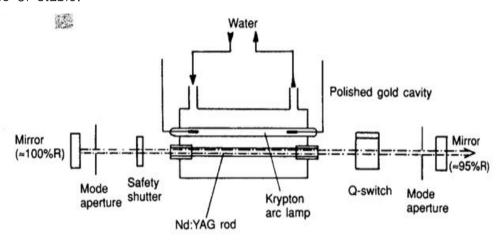


Fig. 2.2 Schematic of Nd:YAG laser

Nd:YAG rod

Actually causing part of the laser light and atoms by high-energy state receive light generated from Krypton Arc lamp was returned to its original state ohmyeonseo laser generates light.

Krypton Arc lamp

Supply that part of the light energy to the Nd: YAG rod, Quartz glass tube inside the injection of the inert gas, Krypton, and applying a high voltage to both electrodes are causes.

O Polished Gold Cavity

Cross-section is oval. Krypton lamp and YAG rod are positioned inside the box that is length 10-15cm, width about 6-7cm. That occurs in the lamp light is reflected from the inner cavity is designed to focus on the YAG rod and to increase the reflectivity inside coated with gold by set.

Water

When the temperature is high, it reduces YAG rod temperature by removing the lamp from the heat generated by the coolant because it reduces the light generation efficiency YAG rod by removing the lamp from the heat generated by the coolant. Also deionized water is used by coolant water.

Mirrors

The intensity of the light generated from the YAG rod YAG rod, depending on the length proportional to the increase in length to achieve the same effect as a constant YAG rod, install mirrors on both sides of the YAG rod and the light reflected repeatedly YAG rod to pass through. Dozens or hundreds of times in such a way that YAG rod light passing through the century be strong enough to have some limit is reached, right 95% of the reflections in the mirror Donghae 5% bip laser output balchul. Of 5% of the light output is utilized in the actual laser processing.

Others

Mode Aperture adjust the shape of the beam, Q-switch is used for the output of pulse-shaped beam.

2.2.3 Welding parameters of Nd:YAG Laser Welding

Standard of judgement of laser welds is lack of welding, status of structure and shape of welds(depth of penetration, shape of cross section). Also there are some parameters that are laser paremeter, process of parameter and welding material parameter.

- 1) Laser parameter
- · laser power
- · focus diameter
- · laser beam mode
- 2) Process parameter
 - focus position
- · focused spot size
- · depth of focus
- · shielding gas

2.2.4 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).

2.3 Laser Stitch Welding

- · Welded qualification and strength are superior to spot welding.
- · Welds is smaller than spot welding.
- · Loss of material is less than spot welding.
- Design can be freely.
- · Reduction of weld locations and simplify work processes.
- In spite of the initial cost of installation is expensive, the welding speed is fast and weldability is very good.
- Improvement of fuel efficiency.
- Reduction of production costs.

2.4 Characteristics of Objective Materials

2.4.1 Objective Material

The materials used for this study are SGACC 60/60 and SGARC 340. Those materials are made to supplement strength. Therefore manufacturing process of cold rolled sheet and chemicals are shown to study mechanical and metallurgical characteristics. Chemical composition and mechanical properties of base metals are given in Table 2.1 and 2.2 respectively.

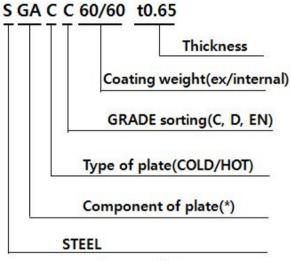
Table 2.1 Chemical compositions in SGACC 60/60 and SGARC 340

Material	Chemical Composition(Wt%)						
Materrar	С	Si	Mn	Р	S	Ti	S-AL
SGACC 60/60	0.0013	0.003	0.094	0.01	0.005	_	0.05
SGARC 340	0.001	0.048	0.005	0.01	0.43	TR	0.033

Table 2.2 Mechanical properties of SGACC 60/60 and SGARC 340

Material	Y.S(N/m²)	T.S(N/mm²)	Elongation(%)
SGACC 60/60	152	299.1	45
SGARC 340	198.1	358.9	39.4

2.4.2 Orthography of Products



*EF: Fe-Zn electric gilding
*GA: Galvannealed(Zn-Fe)

*ZF : Zn-Fe alloy

1)Product specification

Table 2.3 Material symbol of SGACC 60/60 and SGARC 340

Material symbol					
HMC	KMC	POSCO	NKK	KSG	NSC
SGACC	SBHG1A	CGCC	PZACC	RAD1	ASC, ASHC
SGARC	_	CGCHS35	PZABKCA35F	RAC340R	AS340R

2)Applications

• To inner and shell of the car and appliances to inner and shell



(a) Inner & outer plates of automobiles



(b) material for painted steel



(c) Furniture



(d) Inner & outer plates of home appliances

Fig. 2.3 Applications to SGACC 60/60 and SGARC 340 industry

Table 2.4 Application parts of SGACC 60/60 and SGARC 340

PART				
Products PART NAME		Function		
SGACC 60/60	F/APRON INR/OTR, HOOD INR,RR FLR, RR C/LAMP HS'G, T/LID INR, S/ABS HS'G	After coating corrosion resistance, Good weldability		
SGARC 340	MBR FR SIDE INR/OTR, COWL TOP OTR, BACK, MBR	R : Strength of reinforced parts E : Excellent elongation		

- * Bake hardening steels can achieve higher strength in the finished part while retaining good forming performance. The gain in yield strength through the "bake hardening" (BH) effect is generally greater than 40 MPa. Thanks to this BH effect, this steel offers two advantages compared to conventional drawing quality steels:
- Improved dent resistance in all finished parts in the case of low forming strains (hood, roof, doors and wings);
- Substantial weight reduction potential at equivalent dent resistance (the decrease in thickness is offset by increased yield strength resulting from the heat treatment process).

Bake hardening steels thus offer a suitable response to automotive bodywork requirements. By providing an excellent drawability-dent resistance combination, they enhance vehicle weight reduction and aesthetics.

2.4.3 Cold Rolled Steel

Cold rolling occurs with the metal below its recrystallization temperature (usually at room temperature), which increases the strength via strain hardening up to 20%. It also improves the surface finish and holds tighter tolerances. Commonly cold-rolled products include sheets, strips, bars, and rods; these products are usually smaller than the same products that are hot rolled. Because of the smaller size of the workpieces and their greater strength, as compared to hot rolled stock, four-high or cluster mills are used. Cold rolling cannot reduce the thickness of a workpiece as much as hot rolling in a single pass.

Cold-rolled sheets and strips come in various conditions: full-hard, half-hard, quarter-hard, and skin-rolled. Full-hard rolling reduces the thickness by 50%, while the others involve less of a reduction. Skin-rolling, also known as a skin-pass, involves the least amount of reduction: 0.5-1%. It is used to produce a smooth surface, a uniform thickness, and reduce the yield point phenomenon (by preventing Lüders bands from forming in later processing). It locks dislocations at the surface and thereby reduces the possibility of formation of Lüders bands. To avoid the formation of Lüders bands it is necessary to create substantial density of unpinned dislocations in ferrite matrix. It is also used to breakup the spangles in galvanized steel. Skin-rolled stock is usually used in subsequent cold-working processes where good ductility is required.

Other shapes can be cold-rolled if the cross-section is relatively uniform and the transverse dimension is relatively small. Cold rolling shapes requires a series of shaping operations, usually along the lines of sizing, breakdown, roughing, semi-roughing, semi-finishing, and finishing.

If processed by a blacksmith, the smoother, more consistent, and lower

levels of carbon encapsulated in the steel makes it easier to process, but at the cost of being more expensive.

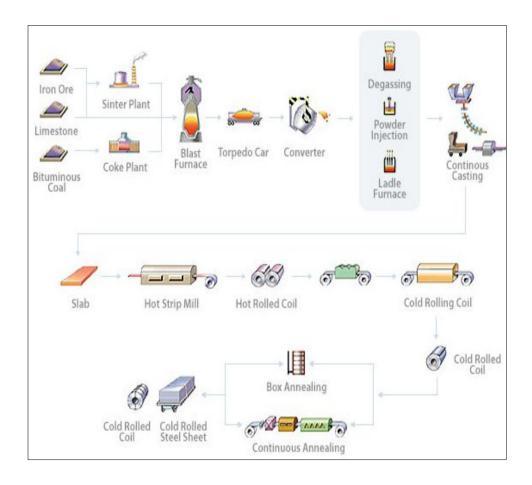


Fig. 2.4 Manufacturing Process of Cold Rolled Sheet

2.4.4 Galvannealed Steel

Galvannealed sheet is carbon steel sheet coated with zinc on both sides by the continuous hot dipped process. Immediately as the strip exits the coating bath, the zinc coating is subjected to an in-line heat treatment that converts the entire coating to a zinc-iron alloy. Conversion to the alloy results in a non-spangle matte finish which makes the sheet suitable for painting after fabrication. After post painting with proper selected primers and paints, the combined paint/galvannealed coating offers excellent resistance to peeling and/or blistering of the paint in addition to long lasting corrosion resistance compared to conventional galvanized sheet.

Chapter 3

Experiment Method of Spot and Laser Stitch Welding Process

3.1 Details of Spot and Laser Stitch Welding System

3.1.1 Spot Welding Equipment and Experimental Setup

Spot welding equipment was used by compressed air type machine(100KVA). And there are welder and specifications in Fig. 3.1 and Table 3.1.



Fig. 3.1 Spot welding equipment

Table 3.1 Specifications of spot welding equipment

Model	Rated input (kVA)	Power input voltage (V)	Max welding input (kVA)	Max electrode force (kgf)	Rated output (A)	Electrode diameter (mm)	Cooling capacit y (ℓ/min)
MA- 201M	100	220 (60Hz)	241	1000	27000	6	10

3.1.2 Nd:YAG Laser Stitch Welding Equipment and Experimental Setup

Laser equipment used in this study is a CW (continuous wave) Nd: YAG laser. This device and main specifications are shown in Fig. 3.2 and summarized in Table 3.2 respectively. This equipment has a maximum output 3kw, beam quality 25mm·mrad and six cavity.

Laser beam is transmitted through the fiber cable. The beam diameter of 600 μ m laser light cable was used.

In the present study, the experiments were carried out by laser power 1~3kw. The laser head was used on mounted 6-axis robot and the location of the focal point matched on the upper surface of material. The laser system is shown in Fig. 3.3.



Fig. 3.2 Nd:YAG laser equipment

Table 3.2 Specification of Nd:YAG laser welding equipment

Model	HL3006D			
Type	CW Nd:YAG Laser			
Function	Unit	Spec.		
Wave length of the laser light	nm	1064		
Maximum output power	W	4000		
Laser power applied to workpiece	W	3000		
Minimum output power	W	30		
Beam quality	mm·mrad	25		
Laser light cable	μm	600		
Length of laser light cable	m	30		
Power consumption	kw	92		
Cavity number	EA	6		
Cooling water temp. range	ာ	6–17		
Weight	kg	3968		
Dimensions W×H×D	mm	3850 × 1630 × 770		
Ambient temp.	Ĉ	10-40		



Fig. 3.3 Laser welding system

3.2 Objective Material

In this study, it is compared to weldalility, mechanical and metallurgical characteristics of spot and laser stitch welding with SGACC 60/60 and SGARC 340. The property was shown in Table 3.3 and 3.4.

Plate of the shear specimen based on KS B 0850 was used in the experiment. Dimensions of specimens were $270 \times 105 \times 0.65$ (mm) and welded by overlap of 35mm of each plate.

Table 3.3 Chemical compositions in SGACC 60/60 and SGARC 340

Material	Chemical Composition(Wt%)							
	С	Si	Mn	Р	S	Ti	S-AL	
SGACC 60/60	0.0013	0.003	0.094	0.01	0.005	-	0.05	
SGARC 340	0.001	0.048	0.005	0.01	0.43	TR	0.033	

Table 3.4 Mechanical properties of SGACC 60/60 and SGARC 340

Material	Y.S(N/mm²)	T.S(N/mm²)	Elongation(%)
SGACC 60/60	152	299.1	45
SGARC 340	198.1	358.9	39.4

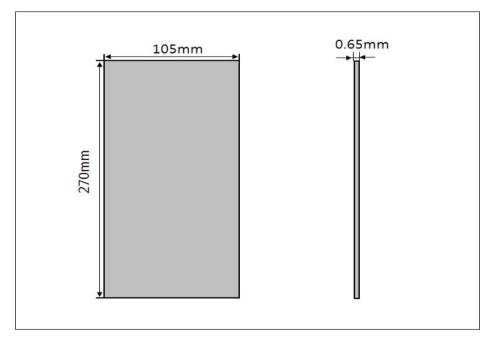


Fig. 3.4 Schematic of specimen dimension

3.3 Experimental Procedure

3.3.1 Spot Welding Condition

Experiments were conducted by using welding current and welding time factor as a major process in this study. Welding current was 16~21kA and welding time was 50~99cycle. And increased current and time were each 1kA and 10 cycle. Also spot welding was carried out by each conditions. this conditions were shown in Table 3.5. Electrode diameter used 6mm in spot welding and R type was used.

Table 3.5 Welding parameters of spot welding

Nugget Squeeze		First welding			Second welding			
diameter (mm)	Force (MPa)	time (cycle)	Current (kA)	Welding time (cycle)	Cooling time (cycle)	Current (kA)	Welding time (cycle)	Cooling time (cycle)
6	800	70	16~21	50~99	10	16~21	50~99	10

3.3.2 Laser Stitch Welding Condition

Focal position were based on the specimen surface and used Ar gas as shielding gas of the flow rate of $15\ell/mim$. The main process factors were the laser power, bead length, welding speed, pitch and each conditions were laser 1~3kw, bead length 10~30mm, welding speed 1~8m/min, pitch 70~105mm.

In addition, each conditions were carried out increseing the laser output 1kw, the beads length 10mm, the welding speed 1m/min and pitch 10mm. A schematic diagram and the actual welding pictures were shown in Table 3.6 and Fig. 3.5.

Table 3.6 Welding parameters of laser stitch welding

Power (kw)	Forcal depth (mm)	Shielding gas (ℓ/mim)	Welding speed (m/min)	Bead length (mm)	Pitch (mm)
1~3	0	15	1~8	10~30	70~105



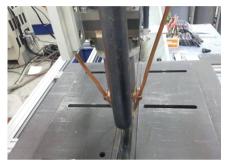


Fig. 3.5 Experimental setup for laser stitch welding

3.3.3 Conditions of Laser Stitch Welding to Compared with Spot Welding

To compare the shear strength of spot welding and laser stitch welding were carried out on the specimen of $270\times105\times0.65$. And welding parameters were bead length and pitch. First junction was performed under the same conditions, 19kA 99cycle 19kA 99cycle spot welding conditions and shear conditions similar to spot welding and laser stitch welding bead length was 10mm, 2kw 3m/min. Also laser stitch welding about bead length of 20mm, pitch of 70, 80, 90mm and bead length 30mm of pitch 105mm were conducted by the each conditions and the mechanical characteristics were compared. There were schematics in Fig. 3.6 and 3.7.

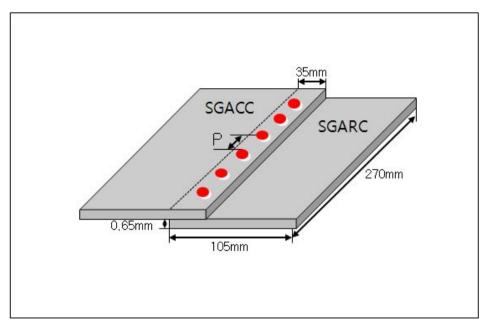


Fig. 3.6 Schematic of spot welding

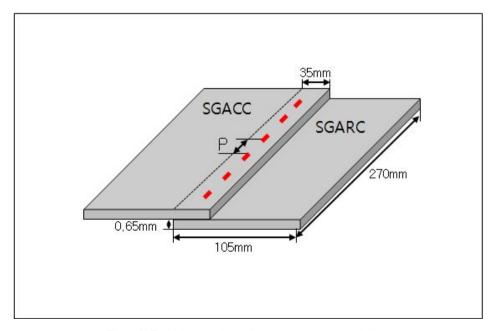


Fig. 3.7 Schematic of laser stitch welding

3.4 Evaluation of Mechanical and Metallurgical Characteristics

3.4.1 Shear Test

Shear test was carried out with Dongil-Simaz Universal Testing Machine (EHF-EG200KN-40L) using WINSERVO program. Fig. 3.8 shows the EHF-EG200KN-40L and tensile testing setup.

The specimens are fabricated in accordance with the Korean Industrial Standards (KS0851). The specimen dimensions are given in Table 3.7 Shear test was done with Load speed 0.08333mm/sec and stress-strain curve was obtained.

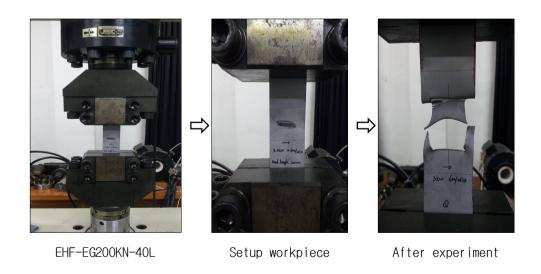


Fig. 3.8 Process of shear test

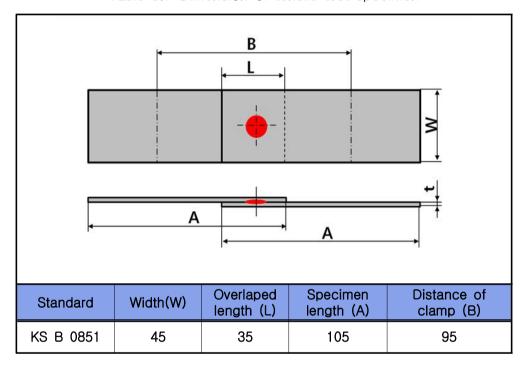


Table 3.7 Dimension of tensile test specimen

3.4.2 Hardness Test

The hardness of welded specimen was measured using Akashi HM-112 Vickers Hardness tester as shown in Fig. 3.9 and Table 3.8. 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. 3.10 shows hardness measurement points of welded specimen. The hardness test was carried out on the welded specimen at 0.4 and 0.8 at two different positions.



Fig. 3.9 Micro vickers hardness tester

Table 3.8 Micro vickers hardness tester

	Values
Mode I	Akashi HM-112
Type	Micro vickers hardness tester
Lode	0.5kgf
Loading time	10sec



Fig. 3.10 Hardness measurement points of welded specimen

3.4.3 Microstructure Analysis

The cross section of spot and laser stitch welding specimen was cut perpendicular to the welding direction. It was polished with 9,3 and 1um diamond paste. Diamond paste was used as the final polishing solution, and then the specimen was chemically etched in Nital 8%(alcohol 92mml + nitric acid 8mml) to observe the microstructure and macro of the joint.

The prepared specimen was mounted on INFINITY optical microscope to observe the micro structure as shown in Fig. 3.11.



Fig. 3.11 Optical microscope

3.4.4 Temperature Distribution Analysis

To observe the distribution of the macroscopic temperature of laser stitch welding and spot welding in this study, the junction was carried out using a thermal imaging camera. Specifications of thermal camera and a thermal imaging camera was used in this study are shown in Fig. 3.12 and Fig. 3.13 respectively.



Fig. 3.12 Thermal CAM_P25

Product S	pecifications
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. 3.13 Specifications of Thermal CAM_P25

Chapter 4

Mechanical and Metallurgical Characteristics of Spot and Laser Stitch Welded Joints

4.1 Optimization of Spot and Laser Stitch Welding

4.1.1 Experiment by Spot Welding

Welding conditions were selected for the BOP (bead on plate) test conducted in the range of welding current of 16 ~ 20kA and part inspection and shear tests were performed for the determination. Shear test inspection and acceptance criteria were bead appearance of the upper and lower plates, fracture geometry. Shear standards applied by the Hyundai-Kia automotive shear criteria. And good welds were got between 18 to 20kA. Therefore, the welding current was 18~20kA and welding time was 50~99cycle. And spot welding was performed as increasing 10cycle. The welding conditions were shown in Table 4.1 and Table 4.2.

Table 4.1 Conditions of BOP test

	First welding		Sec	cond weld		Squeeze		
No.	Current (kA)	Welding time (cycle)	Cooling time (cycle)	Current (kA)	Welding time (cycle)	Cooling time (cycle)	Force (MPa)	time (cycle)
1	16			16				
2	17			17				
3	18	99	10	18	99	10	800	70
4	19			19				
5	20			20				

Table 4.2 Conditions of spot welding

Fi	First welding		Sec	ond weldi	ng	_	Squeeze
Current (kA)	Welding time (cycle)	Cooling time (cycle)	Current (kA)	Welding time (cycle)	Cooling time (cycle)	Force (MPa)	time (cycle)
	50			50			
	60			60			
18	70	10	18	70	10	800	70
10	80	10	10	80	10	600	70
	90			90			
	99			99			
	50			50		0 800	70
	60	10	19	60	10		
19	70			70			
19	80			80			
	90			90			
	99			99			
	50			50			
	60			60			
200	70	10	20	70	10	800	
20	80	10	20	80	10		70
	90			90			
	99			99			

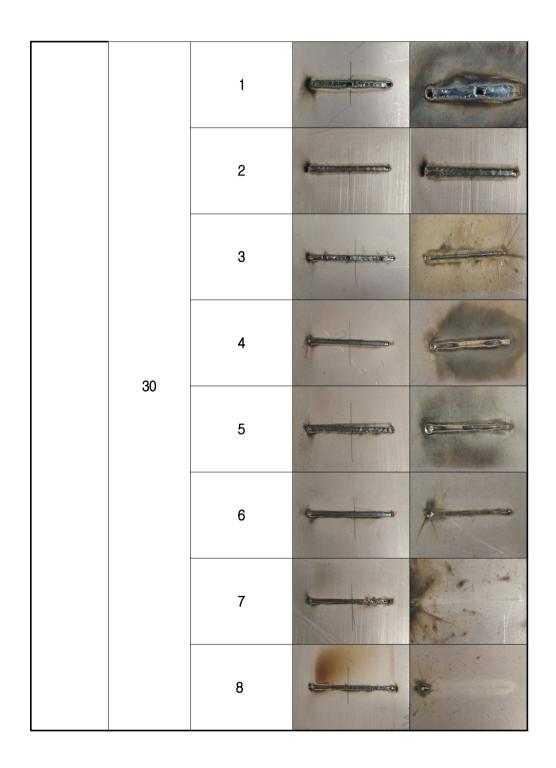
4.1.2 Experiment by Laser Stitch Welding

Laser stitch welding was conducted by the laser output 1~3kw, bead length 10~30mm, welding speed of 1~8m/min as increasing 1kw, 10mm, 1m/min. Using the criteria was done as the same way of Criteria of spot welding. Also laser stitch welded joints is evaluated based on the welding defect standard(EN ISO13919-1) for electron beam and laser welding. And laser stitch welding conditions and bead appearance were shown in Table 4.3.

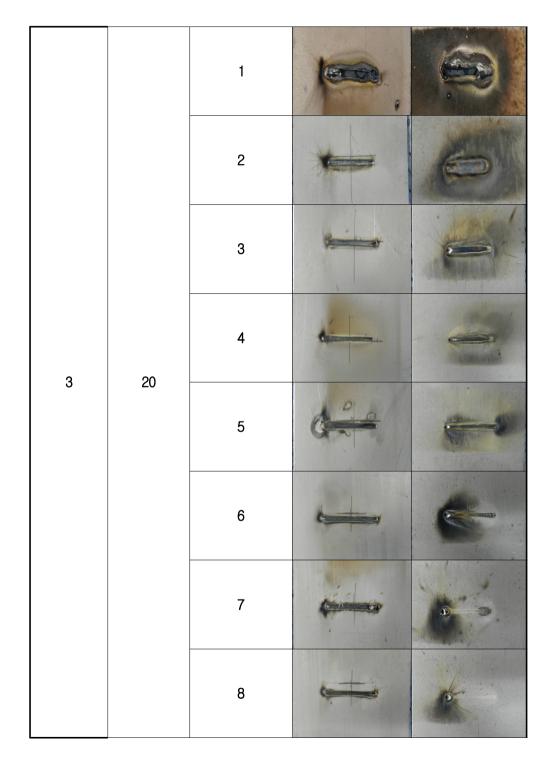
Table 4.3 Conditions of laser stitch welding

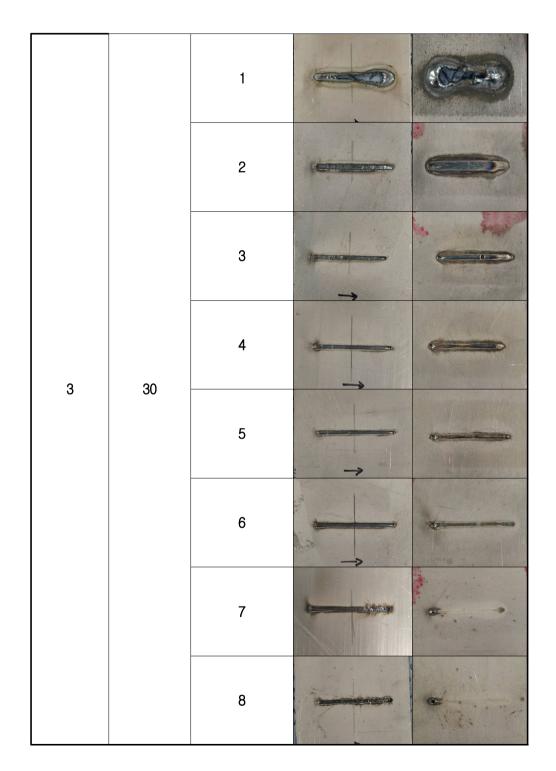
Laser power (kw)	Bead length (mm)	Welding speed (m/min)	Top bead	Bottom bead
	10	1		
1	20	1		
,	30	1		
		2		
2	10	1		

	2	
	3	
	4	
	1	
	2	
20	3	
	4	
	5	*









4.1.3 Comparison of Bead Profiles of Spot Welding and Laser Stitch Welding

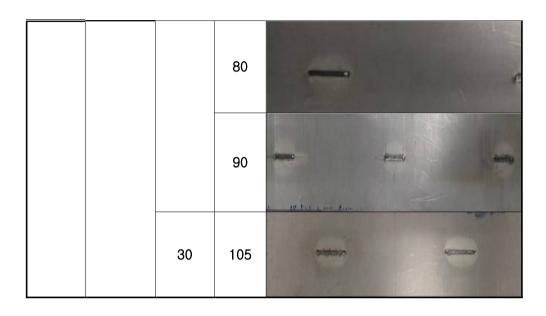
The specimen of $270\times105\times0.65$ were carried out each weld. conditions of spot welding were 19kA 99cycle and conditions of laser stitch welding were bead length 10mm, 2kw 3m/min, bead length 20mm, pitch 70, 80, 90mm and bead length 30mm, pitch 105mm. And joints were conducted by using spot and laser stitch welding conditions. Welded specimens were shown in Table 4.4 and 4.5.

Table 4.4 Bead appearance of spot welded joints

Force	First welding		Second welding		Bead appearance					
(MPa)	Cur (kA)	W.T (cycle)	Cur (kA)	W.T (cycle)			oud up	JOUT 411		
800	19	99	19	99	9	0	0	•	•	

Table 4.5 Bead appearance of laser stitch welded joints for various welding parameters

Laser power (kw)	Welding speed (m/min)	Bead length (mm)	Pitch (mm)	Bead appearance				
2	3	10	45	1 1 1				
	4	20	70					



4.2 Shear Test Results

4.2.1 Shear Srength of Spot Welded Joints

Shesr test of BOP(bead on plate) of SGACC 60/60-SGARC 340 was carried out to understand the shear strength of spot welded joint made at 16~20kA and 99 cycle(Table 4.6). Testing was carried out as shear strength standards of Hyundai-Kia motors. This result was used as a reference for the testing of spot welded joints. The shear test results were shown in Table 4.6. The shear strength of BOP(bead on plate) was obtained over the standards in 18~20kA and specimens were destroyed as interfacial fracture in 16~17kA and tear fracture in 18~19kA. Also it occurred the expulsion in 20kA. After then spot welding was carried out from the results of BOP.

The shear test results were shown in Table 4.7 and Fig. 4.1, 4.2. Interfacial

fracture was occurred below the 18kA 80cycle 18kA 80cycle. There were tear and plug fracture over the 18kA 90cycle 18kA 90cycle and expulsion over the 20kA. Although most of the section over the 18kA satisfied standard except for 18kA 60cycle 18kA 60cycle and 18kA 70cycle 18kA 70cycle, interfacial fracture and expulsion is ignored due to the lack of penetration and reduction of nugget diameter. Consequently best of the shear strength was obtained as 3.64 kN in 19kA 99cycle 19kA 99cycle.

The results of shear strength is shown in Fig. 4.1 and there is optimized graph of shear strength in Fig. 4.2.

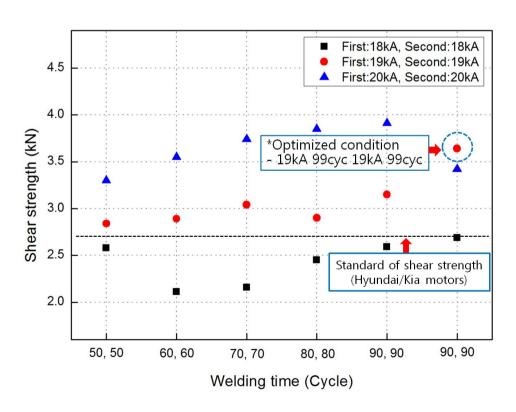


Fig. 4.1 Comparison of shear strength

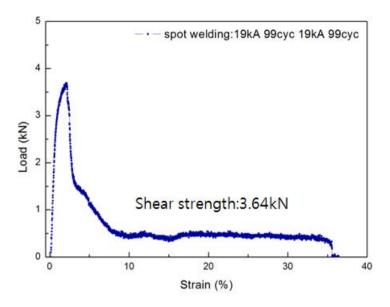


Fig. 4.2 Shear strength of welded joints in optimized welding conditions

Table 4.6 Shear strength of BOP test

Fir	st weld	ding	Seco	nd wel	ding	Force	S.T	Fractured	S.T
Cur (kA)	W.T (cyc)	C.T (cyc)	Cur (kA)	W.T (cyc)	C.T (cyc)	(MPa)	(cyc)	specimen	(kN)
16			16						2.15
17			17					0 0	2.40
18	99	10	18	99	10	800	70	0 0	2.58
19			19					3 6	2.84
20			20					3 6	3.30

Table 4.7 Shear strength of spot welding

Fir	First welding		Second welding			Force	S.T	Fractured	S.T
Cur (kA)	W.T (cyc)	C.T (cyc)	Cur (kA)	W.T (cyc)	C.T (cyc)	(MPa)	(cyc)	specimen	(kN)
	50			50		800	70 -	• •	2.58
	60	0		60					2.11
18	70	10	18	70	10			0	2.16
10	80	10	10	80		800		0 0	2.45
	90			90				0 5	2.59
	99			99				0	2.69

	50			50				1 6	2.84
	60			60					2.89
10	70 10 19 70 19 10 10 800 70	10	10	900	70		3.04		
19	80	10	19	80	- 10	800	70	0 0	2.90
	90			90					3.15
	99			99					3.64
	50	10		50					3.30
	60			60	10	800	70		3.55
20	70		20	70					3.74
20	80		20	80					3.85
	90			90					3.91
	99			99					3.42

4.2.2 Shear Strength of Laser Stitch Welded Joints

As a result of shear strength tests, condition of 1kw 1m/min and bead length 30mm only occurred tear fructure and obtained 5.56kN of shear strength. But other conditions of 1kw were occurred interfacial fracture due to incomplete penetration. Each condition of 2kw obtained the shear strength that meet the criteria in all areas, but bead surface of 1m/min was poor due to the excessive heat input. Also interfacial fracture was occurred in 10mm 4m/min, 20mm 5m/min and 30mm 8m/min due to incomplete penetration. 3kw bead length 20, 30mm that meets the criteria in the shear strength values were obtained. Bead length of 10mm, on the other hand, the condition exhibited the lowest shear strength values.

Bead bead appearance standards that satisfy the shear strength and the length of 20mm, 2kw 4m/min conditions optimal welding conditions were selected. Basis of two to three times more than the results from most of the area, the shear strength value because it represents the experimental results show that the optimum conditions by considering the economic aspects and bead top and bottom exterior. Experimental results was shown Fig. 4.3, 4.4, 4.5 and Table 4.8 respectively. Also there are Optimized graph of shear strength in Fig. 4.6

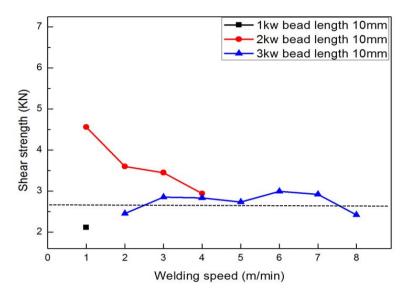


Fig. 4.3 Shear strength of welded joints with welding speed (bead length 10mm)

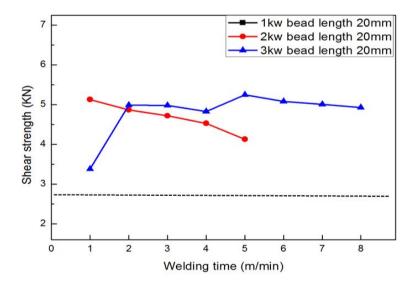


Fig. 4.4 Shear strength of welded joints with welding speed (bead length 20mm)

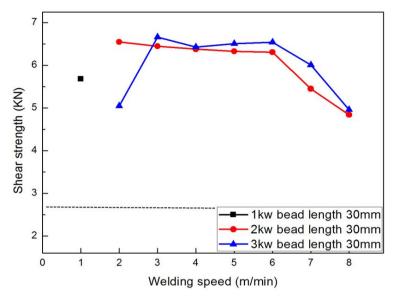


Fig. 4.5 Shear strength of welded joints with welding speed (bead length 30mm)

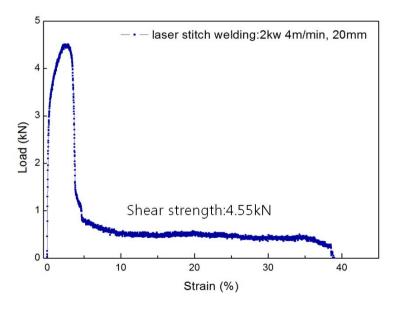


Fig. 4.6 Shear strength of welded joints in optimized welding conditions

Table 4.8 Shear strength of laser stitch welded joints

Laser power (kw)	Bead length (mm)	Welding speed (m/min)	Fractured specimen	S.T (kN)
	10	1	lack of fusion	-
1	20	1	lack of fusion	-
	30	1		5.68
		2		0.20
2	10	1		4.50
		2		3.70
		3		3.53

		4		3.24	
	20		1		5.40
				2	
2		3		4.79	
			4		4.55
		5		4.21	
	30	1	lack of fusion	-	

			2		6.55										
				3		6.45									
		4		6.33											
2	30	30	5		6.38										
			6		6.20										
													7	2 km mmin	5.47
								8		4.84					

		1	lack of fusion	-								
		2		2.45								
	10	10	3		2.85							
3			10	4		2.81						
3			5		2.73							
			6		2.83							
		7		2.84								
												8

	20	1	3.38
		2	5.08
		3	4.94
3		4	4.83
3		5	4.72
		6	4.56
		7	3.75
		8	4.93

3	30	1	lack of fusion	-
		2	1	5.55
		3		6.54
		4		6.44
		5	1	6.51
		6		5.85
		7	†	5.20
		8		4.96

4.2.3 Comparison of Shear Strength of Spot and Laser Stitch Welded Joints

Laser stitch welding pitch (45mm) in the same shear tests shear strength was able to confirm that improved approximately 31% compared to spot welding. But the interfacial fracture was occurred in laser stitch welding.

Therefore, the optimal welding conditions 4.83kN shear strength to the junction with the value of the bead length 20mm, 2kw 4m/min conditions was conducted. Experimental results were similar about 16~17kN in the bead length 10mm, seams of 6 points, bead length 20mm, seams of 3 points and bead length 30mm, seams of 2 points 20mm. And total bead length of welded joints of each conditions was in the same.

Also, spot welding pitch more than doubled to a 26% increase in the shear strength could be found. Experimental results were shown in Table 4.9, 4.10 and Fig. 4.7.

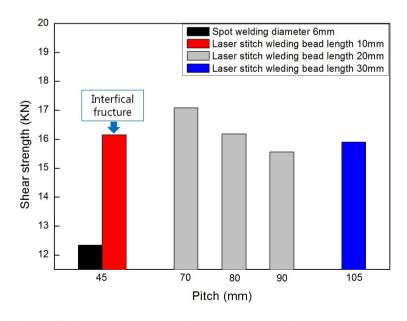


Fig. 4.7 Shear strength of welded joints for various pitch

Table 4.9 Fractured specimen of optimized spot welded joints after shear test

First v	velding		cond ding	Fractured specimen			S.T			
Cur (kA)	W.T (cycle)	Cur (kA)	W.T (cycle)		Tract	.ureu	3pecii	11611		(kN)
				0	9	6	A	0	P	
19 99	19	19 99	() NZ 33 W230	6	Ø	3	9	0	12.34	

Table 4.10 Fractured specimen of laser stitch welded joints after shear test

Laser power (kw)	Welding speed (m/min)	Bead length (mm)	Pitch (mm)	Fractured specimen	S.T (kN)
	3		45		16.15
		20	70		17.08
2			80		16.18
4	4		90		15.56
		30	105		15.90

4.3 Hardness Test Results

Hardness of welding zone was higher than base metal in case of spot welding. SGACC 60/60 was high over 60Hv and 15Hv in SGARC 340. The hardness of welding zone was rising rapidly because cause is rapidly cooled by the coolant inside the spot welder.

Hardness of SGARC 340 compared to SGACC 60/60 rises sharply. Because SGARC 340 is BH(Bake Hardening), the hardness increased sharply.

SGACC 40/40 is cold rolled steel. Therefore, structure of this steel was grain coarsening and hardness was increased due to rapidly colling effect, when the steel was welded. Also welding zone and HAZ were widely distributed and nugget diameter was measured as 7.5mm. Hardness distributions of spot welding are shown in Fig. 4.8.

Hardness of welding zone of laser stitch welding was positively correlated with the 80Hv and distribution of welding zone and HAZ is considerably narrow.

When the hardness was compared to spot welding and laser stitch welding, haedness of laser stitch welding was higher than spot welding over 20Hv and area of welding zone of laser stitch welding was less than spot welding as one-eighth substantially. The hardness distribution is shown in Fig. 4.8, 4.9 and 4.10 respectively.

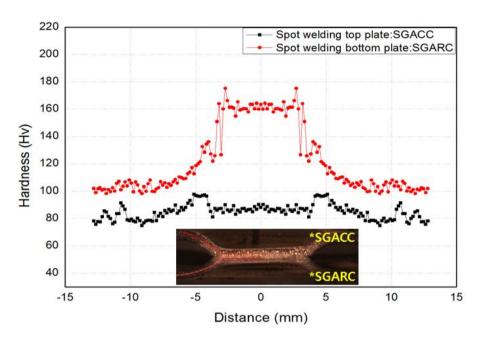


Fig. 4.8 Hardness distribution of spot welded joints

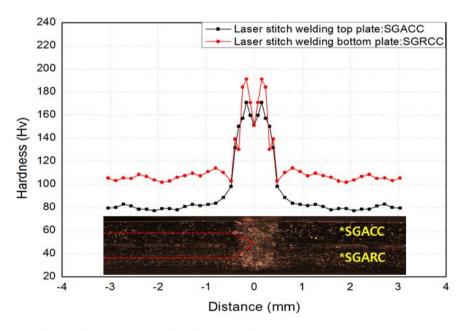


Fig. 4.9 Hardness distribution of laser stitch welded joints

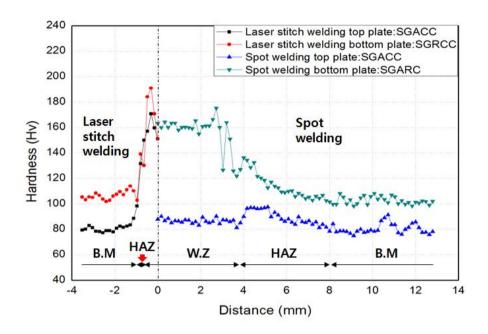


Fig. 4.10 Comparison of hardness distribution of spot and laser stitch welded joints

4.4 Measured Temperature Distribution Results

Macroscopic temperature distribution of laser stitch welding and spot welding was measured through thermal imaging cameras. Welding zone, HAZ, base metal was measured.

Colling time of laser stitch welding was 160 seconds and 65 seconds in spot welding. Laser stitch welding was confirmed that the measure was being cooled more rapidly than the spot welding. Also deformation by heat could be reduced due to rapidly cooling time. so mechanical characteristics of laser welding is superior to the spot welding. The results are shown in Fig. 4.11, 4.12 and 4.13.

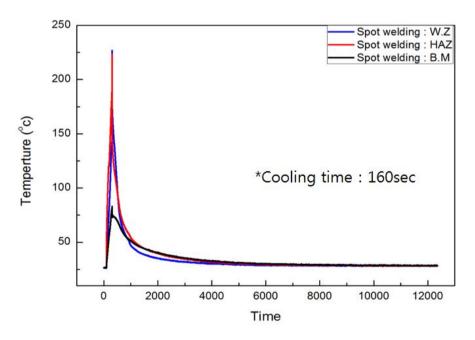


Fig. 4.11 Temperature distribution of spot welded joints

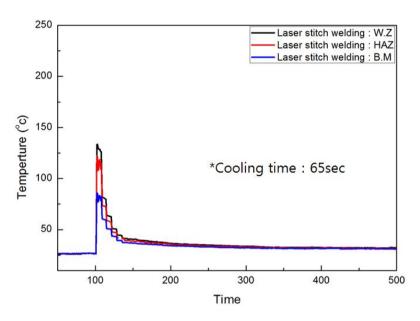


Fig. 4.12 Temperature distribution of laser stitch welded joints

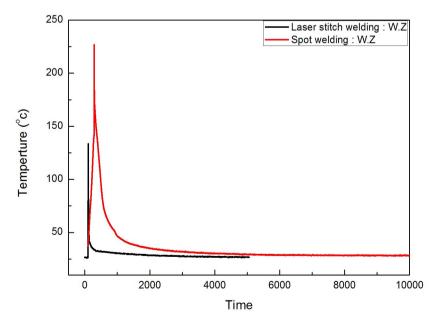


Fig. 4.13 Comparison of temperature distribution of spot and laser stitch welded joints

4.5 Microstructure Analysis

4.5.1 Microstructure of Spot Welding

Nugget diameter of spot welding was measured in 7.5mm. (d) of the microstructure than the organization of (a) fine because it could be confirmed that the high hardness and welding zone of (b) recrystallized due to cold-rolled steel sheet, so during joining the microstructure is coarsening by the cooling effect of the electrode and hardness was increased. Also hardness of (c) was high and microstructure was refinements. The junction strength of SGARC 340 is rising rapidly because of BH steel sheet. Microstructure of (f) through the hardness distribution and the temperature distribution was refinements and melting section (e) of the microstructure that consists of martensite and bainite. Shear testing of tear fracture occurs, but also complete penetration in the melt did not occur could be confirmed by SEM observation. Microstructures is shown in Fig. 4.14, 4.15 respectively.

The SEM images of the fractured surface was observed for weld joints by spot welding in Fig. 4.16. The fracture surface shows a dimple pattern. Therefore it is subjected to ductile fracture. In addition the tear fracture was occurred after shear, but complete penetration in the melt did not occur could be confirmed in Fig. 4.17.

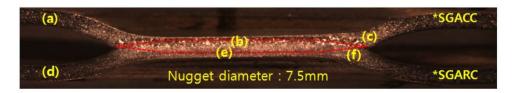


Fig. 4.14 Cross section of welded joints

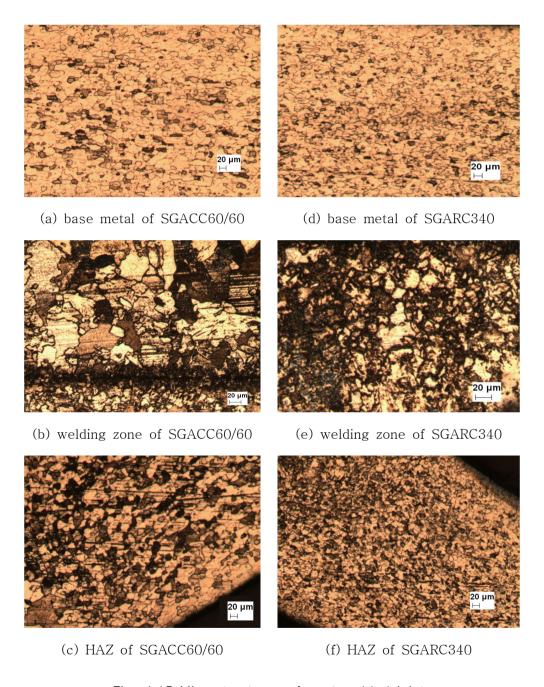


Fig. 4.15 Microstructures of spot welded joints

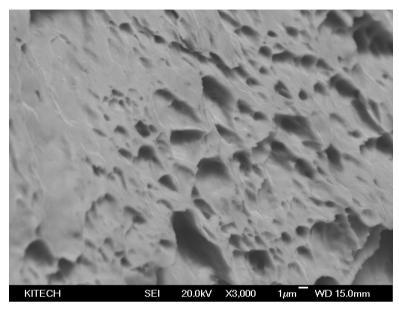


Fig. 4.16 SEM image of fractured surface of spot welded joints after shear

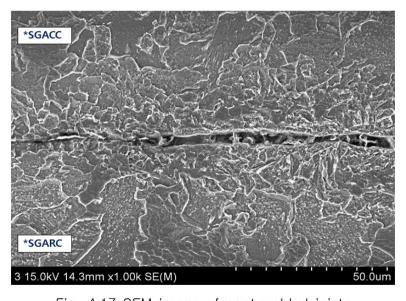


Fig. 4.17 SEM image of spot welded joints

4.5.2 Microstructure of Laser Stitch Welding

Laser stitch welding at the junction diameter was measured to 0.85mm. Microstructure of (a), (b) is in the same like spot welding and organization of (b), (e) consist of martensite and bainite due to rapidly cooling effect. The organization of (c), (f) was coarsening and finely distributed. Cross section and microstructure is shown in Fig. 4.18 and 4.19.

The SEM images of the fractured surface was observed for weld joints by spot welding in Fig. 4.20. The fracture surface shows a dimple pattern. Therefore it is subjected to ductile fracture.

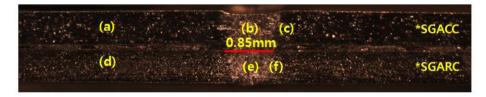


Fig. 4.18 Cross section of laser stitch welded joints

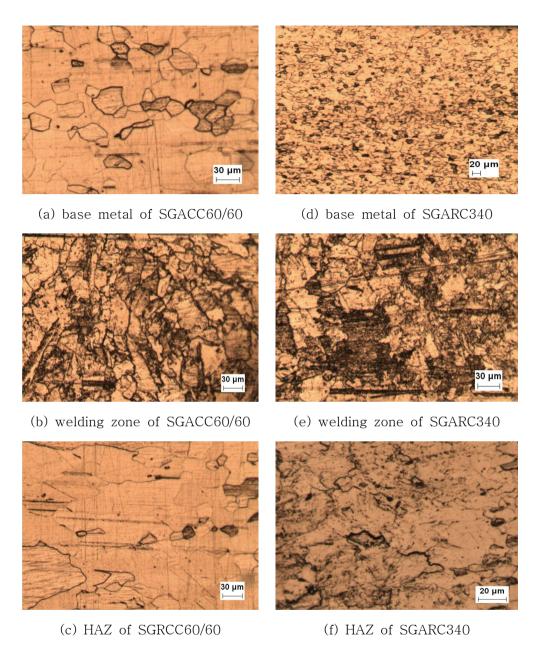


Fig. 4.19 Micro structures of laser stitch welding joints

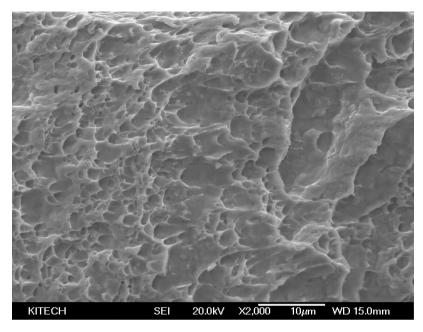


Fig. 4.20 SEM image of fractured surface of laser stitch welded joints after shear

Chapter 5

Conclusion

Laser stitch welding were successfully carried out to join SGACC 60/60 and SGARC 340. In order to investigate the weldability of laser stitch welded joints, mechanical test(shear test, hardness test) and microstructural analysis have been carried out. Moreover, a comparative study has been carried out between spot and laser stitch welded joints.

From this study conclusions are made as follows:

- (1) The welding conditions were determined by evaluating the effect of welding process variables(laser power, welding speed, pitch) based on the welding defect standard(EN ISO 13191-1) for electron beam and laser welding.
- (2) The optimum conditions for laser stitch welded joints of SGACC 60/60 and SGARC 340 steel plate is laser power of 2kw, welding speed of 4m/min, shielding gas of 15m/min, focal length of 0mm.
- (3) The shear strength of laser stitch welded joints is about 4.55kN. Welded joints is fractured by tear fracture.
- (4) It is found that shear strength of laser stitch welded joints was 38% higher than that of spot welded joints. When pitch is more than twice of

the spot welded joints, the shear strength of laser stitch welded joints is increased by 26%. Therefore shear strength of laser stitch welded joints is superior to that of spot welded joints. And pitch can be freely adjusted with the structure of automotive cowl.

(5) When compared with welded area(W.M, HAZ) of spot welded joints, those of laser stitch welded joints can be reduced to one-eighth of spot welded joints. Therefore it is though that flange dimensions of automotive cowl can be reduce over 10mm compared with that of spot welded joints.

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논문제목	계적 특성							
	영어 : Mechanica	al Chara	acteristics on	Welded	Joints of			
	Automative Cowl 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()

2013 년 2월

저작자 : 김 형 일



또는 인)

조선대학교 총장 귀하