PERFORMANCE OF GROUTED SLEEVE CONNECTORS IN PRECAST WALL UNDER FOUR POINT LOAD TEST

SITI NORZALIAH BINTI MOHD HAKIMI

Report submitted in partial fulfilment of the requirements for the award of the degree of
B.Eng (Hons.) Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

JUNE 2014

ABSTRACT

The need to investigate the use of precast concrete connections is a topic of growing demand. The precast structural members are normally connected via lapping of reinforcement bar. However, the large numbers of connections that are required in precast concrete system pose problems in term of strength and the failure of the connection. The application of grouted splice sleeve connectors in the market is fast gaining popularity. The adoption of existing splice sleeve connectors are not economics as these connectors in the market are proprietary and purchased from foreign country. The stability of precast concrete structure depends on the continuity between the structural member and the connection, thus the connection must exhibit the ability of transferring loads, possess sufficient strength and ductility and easy to handle and simple to erect. In this research, the connections were the main criteria to be observed based on their performance, shear, bending and the connection failure. This research aims to develop a connection in precast wall by using different number of grouted sleeve connectors, to test the bond strength of a connection with spiral bar connectors in the wall under four point bending test and to determine the types and behavior of failure that may occur in the connection and wall panel. Based on the study conducted, the connectors were inserted in three precast wall with same size each to form one wall panel. These wall panels were tested under four point bending test in order to review the performance of the connection between the walls. In four point bending test, a uniform maximum two point loads were applied on the top of the wall panel to check the connection failure and shear failure in the wall. After tested, the results show that the grout failure occurred on the gap between the wall connections. There was deflection on the precast wall panel and no shear failure occurred at the supports. The reinforcement bar inside the steel pipe for the wall specimen with two connectors slipped before fractured.

ABSTRAK

Keperluan untuk mengkaji penggunaan sambungan konkrit pratuang merupakan antara topik yang menjadi permintaan yang semakin meningkat. Struktur-struktur pratuang biasanya disambungkan melalui kaedah pembalutan bar tetulang. Walau bagaimanapun, bilangan sambungan yang banyak diperlukan dalam sistem konkrit pratuang menimbulkan masalah dari segi kekuatan dan kegagalan sambungan. Penggunaan penyambung sambat lengan yang diturap di pasaran semakin popular. Penggunaan penyambung lengan sambat yang terdapat di pasaran tidak berpatutan sebagai penyambung kerana merupakan hak milik pencipta dan perlu dibeli dari negara asing. Kestabilan struktur konkrit pratuang bergantung kepada kesinambungan antara struktur dan sambungan, oleh itu sambungan mesti menunjukkan keupayaan memindahkan beban, memiliki kekuatan yang tinggi dan kemuluran dan mudah untuk dikendalikan dan didirikan. Dalam kajian ini, sambungan adalah kriteria utama yang perlu dipatuhi berdasarkan prestasi penyambung, ujian ricih, lenturan dan kegagalan sambungan. Kajian ini bertujuan untuk memperkenalkan sambungan di dinding pratuang dengan menggunakan bilangan penyambung sambat lengan diturap yang berbeza, untuk menguji kekuatan ikatan sambungan dengan penyambung bar lingkaran dalam dinding di bawah ujian lenturan dan untuk menentukan jenis dan tingkah laku kegagalan yang mungkin berlaku dalam penyambung dan panel dinding. Berdasarkan kajian yang dijalankan, penyambung dimasukkan ke dalam tiga dinding pratuang dengan saiz sama setiap untuk membentuk satu panel dinding. Panel dinding telah diuji di bawah ujian lenturan untuk mengkaji semula prestasi sambungan antara dinding. Dalam ujian tersebut, beban maksimum dan dua titik telah digunakan pada bahagian atas panel dinding untuk memeriksa kegagalan sambungan dan kegagalan ricih di dinding. Selepas diuji, keputusan menunjukkan bahawa kegagalan turap itu berlaku pada jurang antara sambungan dinding. Terdapat pesongan pada panel dinding pratuang dan tiada kegagalan ricih berlaku di penyokong. Bar tetulang di dalam paip keluli bagi spesimen dinding dengan dua penyambung susut sebelum patah.

TABLE OF CONTENTS

CHAPTER 3 RESEARCH METHODOLOGY

CHAPTER 4 RESULTS AND ANALYSIS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

α	Angle to the axis
σ	Stress
ε	Strain
E	Young Modulus
U	Ultimate bond stress
f_n	Lateral confining pressure
$f_{c'}$	Concrete compressive strength

LIST OF ABBREVIATIONS

AC	Acceptance criteria
ACI	American Concrete Institute
BRC	British reinforcement core
BS	British standard
CCD	Concrete capacity design
LVDT	Linear variable differential transformer
USB	Uniform bond stress

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Precast concrete can be defined as concrete which has been prepared for casting, cast and cured in a location before transported to site. Precast concrete can be differentiated from cast-in-situ by its stress and strain response to external and internal effects. The precast concrete concept in construction industry is having a large potential for the future because it involved prefabrication process. This is because it can make the construction work faster, more economical, environmental friendly and higher quality. The precast concrete is designed to suit the future demands for a commercial, industrial, civic, and domestic building with higher specifications and performance of precast concrete structure. A stable and safe precast building structural system can be formed after the joints are well connected between the structural members. Therefore, connections are important thing to be considered in precast concrete design and construction.

In Malaysia, the precast structural members are commonly connected by lapping of reinforcement bar. However, there is also use of mechanical connector but it is expensive and normally most of the mechanical connector comes from foreign company. Mechanical connector also called as splice sleeve. To connect the reinforcement bars at the two sides, they must be grouted or threaded. Usually, the sleeve is filled with non-shrink grout after it is casted in one of the precast element. Hence, the structural continuity can be achieved through the bonding strength of the grout and the reinforcement bars across the sleeve.

Shuhaimi (2012), indicated that the combination of spiral and elongated bar is able to improve the performance of the splice sleeve connections in precast wall structures. In his research, he stated that the use of spiral bar with elongated bar in the splice sleeve connector produced higher shear strength compared to the use of monolithic connection in NMB splice sleeve. This type of connection also can be used to connect other concrete structures. Factors that contributed on the strength of these connections were the use of spiral and elongated bar that provided a strong bond between the grout and the reinforcing bar splice in the connection.

1.2 PROBLEM STATEMENT

Precast concrete presents high quality in structural elements, construction efficiency, and saving in time and overall cost of investment and construction. The performance and capacity of specially designed connections were analyzed in order to prove the advantages and to develop the market for precast concrete structures in the country. To make the structural performance is same as the in-situ casting which is monolithic concrete structure, that is why the design of precast concrete connection to be such way eventually.

The traditional method of connecting reinforced bar is by using the lap splicing technique. However, the laps need to be extended for significant length. This caused it not so suitable for precast concrete systems. Furthermore, lap splices caused rebar congestion. It will then block the flow of aggregates. The use of ordinary method also led to the constraint of raw materials. Besides that, it is also caused continuous use of steel further raising the price of steel in the market. Therefore, to overcome this problem, several splice method such as the mechanical splices have been designed. With mechanical splices available, it reduced and replaced the application of conventional reinforcement bar lapping by using the sleeve system. By considering the advantages on the sleeve system it provides a solution for all the problems stated above.

Unfortunately, the splice sleeve connectors available on the market are registered product. Thus, not many information about the confinement effect and bar strength development are being released. Moreover, the splice sleeve connectors can only be purchased from foreign companies. This will cause the cost of supplying the splice sleeve connectors system to be higher than using the traditional method.

In high-rise precast structures, flexural failure is more probably to occur than shear failure. The actions of lateral wind loads and load-displacement effects concentrate stress at the connections. Then, this situation caused the engaging reinforcement steel bars to endure high tensile stress. Hence, the workability of a splice sleeve connector is generally measured under tensile load, as proposed by previous splice connector researches. In order to achieve its stability and strength of the connector, all the reinforced concrete components must be connected properly.

The failure usually occurred on the precast wall which then tend it to be bend due to shear force acted on it. Due to the lack of scientific knowledge, many failures premature splice connections occur in specimens such as failure or bar slip. The specimen grout connection also could not support the applied tension. Based on AC313, it stated that any splice connector must be evaluated under direct tensile load and should achieve strength more or equal 1.25 of specify yield strength of the reinforcement used.

1.3 OBJECTIVE OF STUDY

The objectives of this research can be summarized as below:

(a) To develop a connection on precast wall by using different connection design of grouted sleeve connectors.
(b) To test the grouted sleeve connector in the precast wall under shear and bending.
(c) To determine the types and behavior of failure that may occurred in the connection.

1.4 SCOPE OF STUDY

The scopes in this study include the following:

(a) The connection design involved the use of spiral bar and longitudinal steel bars as the reinforcement.
(b) The spiral bar was made from R6 while the longitudinal bar used was Y16.
(c) The material used as the connector inside the wall was steel pipe which same in term of length and diameter.
(d) There were only three panels of precast wall used which was control wall panel without connector, with one connector and two connectors.
(e) The compressive strength of the concrete wall specimen during the test was between 30.255 N/mm^2 to 30.887 N/mm^2.
(f) The grout material used for the connection was Sika-215 which flowable mixed with compressive strength of 53.226 N/mm^2 to 57.912 N/mm^2.
(g) These wall specimens were tested under four point tests.
(h) The results obtained from the test was tabulated and presented in graphical method.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The latest and practical method of connecting precast elements to form a structural frame is by extending the reinforcement steel bar from the precast units into the in-situ reinforced concrete. However, in the late 1960, the original grouted sleeve connector has been developed by Dr. Alfred A. Yee. His invention was first used in precast concrete column-tree connections for 38 stories Ala Moana Hotel, Honolulu, Hawaii.

This mechanical connector can be inserted into the precast units and grouted by injection from exterior. This will resulted in a fully continuous reinforcement steel splice with no pockets to patch during erection. It caused the grout to transfer the forces in one bar to another bar to achieve continuity of the reinforcement in the precast structural members.

In designing of precast concrete structures in the construction, the most important factor that needed to be considered is the connection details between the members. The connections between precast building elements such as columns, beams, slabs and walls must be well connected with each other so that the building structure behave monolithically structure as shown in Figure 2.1.

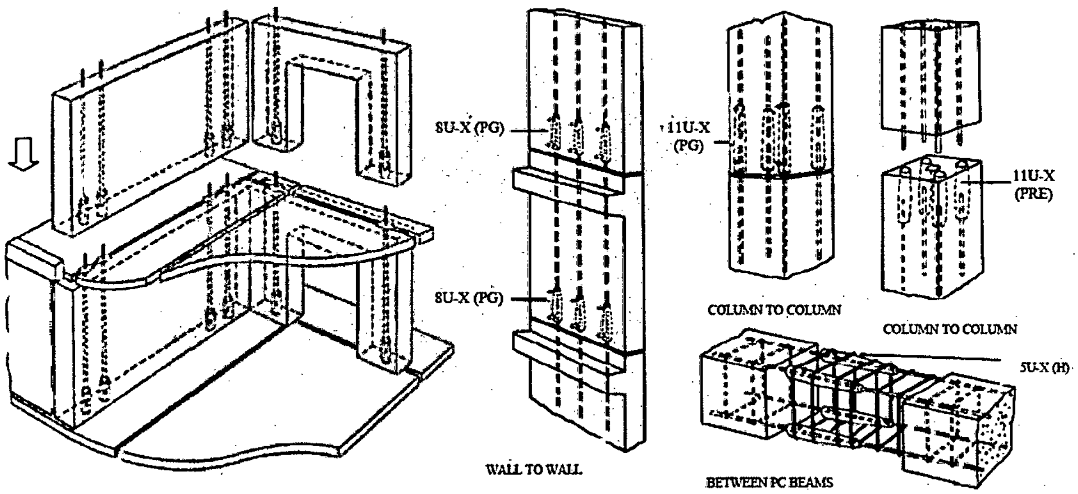

Figure 2.1: The application of splice sleeve connector in precast concrete structure

Source: Splice Sleeve North America, (2003)

This chapter provides some more information about the grouted sleeve connectors and the tests that have been conducted. The mechanism of the bond between bar and concrete is studied and the previous research is also presented. Moreover, further to this, the bond strength and few factors that affected the bond strength based on previous studies are included.

2.2 BOND MECHANISM

For integrity of any reinforced concrete structure, bond between steel and concrete is needed. Despite that, bond is a complicated problem and depends on many parameters. The study and research of bond between steel and concrete has always been famous issue in the field due to its significance for practical design. Bond can also be defined as the gripping effect of an annulus, usually concrete or cement on an embedded length of a steel bar to resist the tendency of forces to slide the bar longitudinally.

According to Untrauer and Henry (1965), bond can be defined as the adhesion of concrete or mortar to reinforcement or to other surfaces where it is placed. Moreover, they also stated that the strength of bond can be defined as the resistance to separation of mortar and cement from the reinforcement bars and other materials in a contact situation. The efficiency of the bonding result can also measure the ability of reinforcement bars in reaching full capacity of bonding strength in the connection.

Walker, Batayneh and Regen (1996), defined that bond transferred stress between the reinforcing bar and the adjacent concrete. The mechanism of bond is now reasonably well understood and accepted. This mechanism is consisted of three separate components which are adhesion between the concrete and the bar, friction due to shrinkage and other effects, and mechanical engaging.

From the many research conducted by scientists regarding the many aspects of bonding, they all agreed that the interaction between the concrete and a bar subjected to a pull-out force is summarized by four different stages as shown in Figure 2.2.

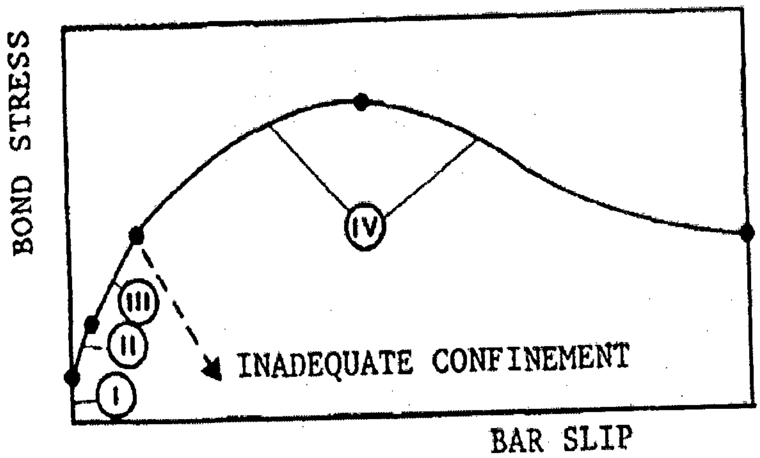

Figure 2.2: Local bond-slip law

Source: Pietro, Gian and Barbara, (1989)

Stage I:
Bond efficiency is assured by chemical adhesion and no bar slip occurs.

Stage II:
The chemical adhesion breaks down, the lugs of the bar induce large bearing stresses in the concrete, transverse microcracks originate at the tips of the lugs allowing the bar to slip, but the wedging action of the lugs remains limited (bonding is assured by the so-called bearing action).

Stage III:
The first longitudinal cracks form as a result of the increasing wedging action of the lugs, which produces tensile hoop tresses in the surrounding concrete. As a consequence, a confinement action is exerted by the concrete on the bars and the bond is assured by bar-to-concrete interlock.

Stage IV:
Once the longitudinal cracks (splitting cracks) break out through the whole cover and bar spacing, the bond fails abruptly if no transverse reinforcement is provided. On the other hand, a sufficient amount of transverse reinforcement would assure bond efficiency in spite of concrete splitting, because of the confinement action developed by the reinforcement.

Abrams (1913), stated that there are two different mechanism of load transfer between the bar and concrete begins, where the movement of sliding resistance takes place. Tangential adhesion of a chemical nature and static friction caused the adhesive resistance to occur. As the sum of these contributions is overcome, a relative movement takes place. While for the bond stress, it develops with a frictional mechanism which is sliding resistance. This mechanism has the same nature respect to the static friction component.

Tassios (1979), said that resistance corresponding to very slow slip values is due to adhesion. Hence, micro-interlocking mechanism between the cement paste and the non-uniformity on the bar surface is activated when the load increases. He also suggested that a progressive cracking in the surrounding concrete is caused by the increasing in bond stress, due to the interlocking mechanism. It then produces the stiffness of embedded bar reduces. So, it can be concluded that as the slip increases, interlocking are gradually destroyed. However, at the same time, a frictional resistance gradually decreases until a residual value reached. Tepfers (1992), also in his research proposed that the interlock mechanism may be explained through an analogous mechanism for bars in the reinforced concrete as shown in Figure 2.3.

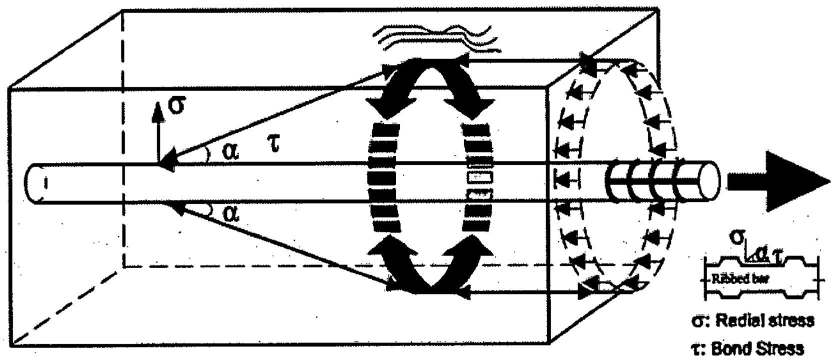

Figure 2.3: Bond behavior of deformed bars, radial component of the bond stress balanced by tensile stresses in the uncracked ring of concrete

Source: Tepfers, (1992)

2.3 BOND STRENGTH

Again, Untrauer and Henry (1965), defined that bond strength as "the resistance to separation of mortar and cement from reinforcing steel and other materials with which it is in contact". They also found that the bond strength between steel and concrete increases linearly with normal pressure. They applied normal pressure to two parallel faces of their specimens together with the pull-out forces. They derived an equation that represents the relationship between the compressive strength of concrete normal pressure and reinforcing bond strength.

2.3.1 Effects of concrete strength on bond strength

The previous research has shown that, for concrete with compressive strength approximately greater than 30 MPa, the bond failure occurs at the surface of the FRP rebar. As a result, the bond strength of FRP reinforcement bar does not influenced greatly by the value of concrete strength, but on the rebar's properties. However, for lower compressive strength concretes which is around 15 MPa, the bond failure mode changes and failure takes place at the concrete matrix interface.

This tendency has been confirmed by Baena (2009), who carried out the tests. Although the concrete strengths were not low enough to produce failure that was caused by damage in the concrete, less damage in the bars and more in the concrete was detected for lower concrete strengths, and vice versa. His results also proved that the bond failure mode of the rebar affected by the strength of the concrete during pull-out. It can be seen that the bond strength is higher when the concrete strength is higher.

Robins and Standish (1984), state that when the concrete strength increases, the bond stress is also increase for similar lateral pressures. When over the range of concrete strengths used, the ultimate average bond strength varied approaching linearly with the square root of the compressive strength. From their investigation, the results of the ultimate pull-out load for lateral pressures of 0, 4, 8 and 12 Nmm^2 for different concrete strength as shown in Figure 2.4.

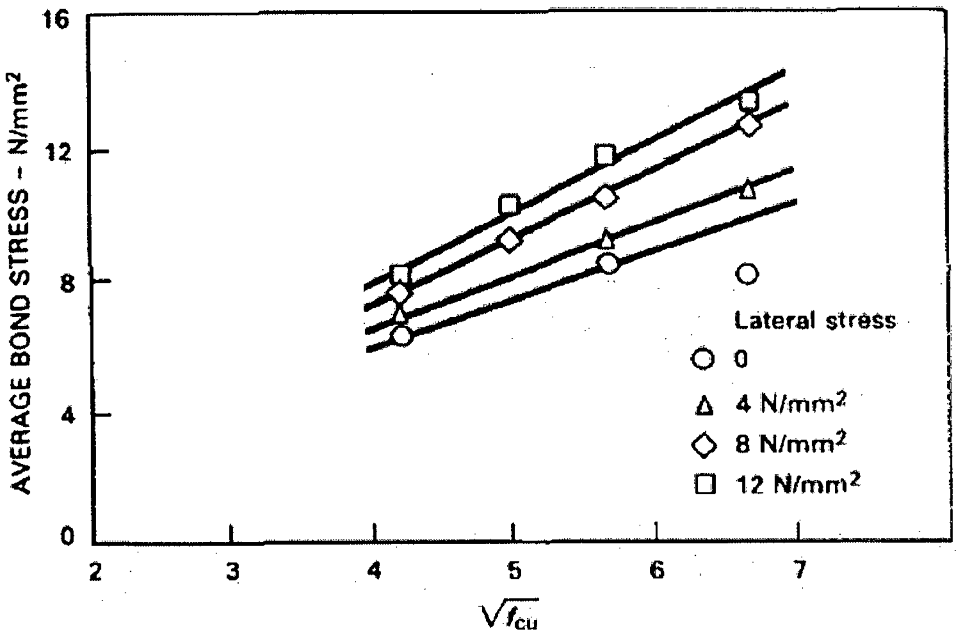

Figure 2.4: Variation of bond strength with square root of cube strength

Source: Robins and Standish, (1984)

2.3.2 Effect of confinement on bond strength

There have been a number of studies on the effects of concrete confinement on the bond behavior and the effective bond strength between reinforcing bars and the surrounding concrete. From a structural point of view, confinement is achieved by applying force in a direction perpendicular to the applied stress. Moreover, confinement can also be achieved by means of transverse reinforcement, by providing thick concrete cover to the main reinforcing bar, or by increasing the spacing between the reinforcing bars.

One of the earliest investigations into the effect of lateral pressure on bond was done by Untrauer and Henry in 1965. They derived an equation that represents relationship between the compressive strength of concrete, normal pressure, and reinforcing bond strength. They found out that the bond strength between steel and concrete increases linearly with normal pressure. They also derived the following equation to describe the bond strength of concrete as a function of its compressive strength $f_{c'}$ and lateral confining pressure f_n:

$$U = (18 + 0.45\sqrt{f_n}\sqrt{f_{c'}}) \quad (2.1)$$

Where

U = ultimate bond stress
f_n = lateral confining pressure
$f_{c'}$= concrete compressive strength

2.4 PROVISIONS OF DESIGN CODE

2.4.1 ACI 318

For evaluating flexural strength and detailing requirements at boundaries of reinforced concrete structural walls, a new provision which is the American Concrete Institute (ACI) Building Code, ACI 318-99 was used. The ACI 318-99 provisions was applied to both slender and stout walls, and walls with openings. The moment capacity of wall cross sections is based on a strain compatibility analysis, and two approaches are provided to determine whether specially detailed boundary elements are required.

The first approach can be applied to all wall sections and involves checking a 0.2 fc¢ stress limit at the wall boundary for code- specified loads. Although the stress limit is the same as that in ACI 318-95, significant changes were incorporated to address commonly identified shortcomings associated with the ACI 318-95 provisions. For the second approach, once the critical section along the wall height is identified, a simplified displacement-based design procedure is used to assess whether special detailing is needed.

2.4.2 AC 133

The scope of the AC133 is mechanical connector systems used to connect uncoated, deformed steel reinforcing bars installed in concrete. The criteria applied to reinforcing bar connectors that are field-assembled onto the ends of reinforcing bars. They have been prepared at a factory or the jobsite. The criteria are also applicable to reinforcing bar connectors that include components that are factory-attached to the reinforcing bars. It is used for final assembly of the connection at the jobsite. Additional requirements, for cementations grouted sleeve steel reinforcing bar connectors.

Connector systems consist of all components utilized to ease coupling of steel reinforcing bars. For example, for coupler systems where a coupler is simply swaged onto the bars, the coupler system component is the coupler. For sleeve-type systems installed with grout, the coupler system typically is the steel sleeve and grout. For systems utilizing a coupler installed onto bars that have specially prepared ends, such as bars with threaded ends, the connector system components are the coupler and the bars.

2.5 STRAIN GAUGE

Strain gauges are available in various shapes and sizes. Apart from different lengths of the measuring grid there are various designs and positions for the connections. There is also a difference between linear strain gauges in single and double (parallel) arrangements, X rosettes with measurement grid axes at 90° to one another, R rosettes with 3 measuring grid axes arranged at certain angles to one another, strain gauge chains and numerous other special shapes. The large number of shapes and sizes is the result of adaptation to different application problems. The selection criteria of strain gauge depend on range of application, types of strain gauge, technical data, and environmental influences.

Mechanical strain gauge occurs relatively rarely. However, they have a long history. Based on their construction, they normally can be applied on larger objects. A trace scratched on a metal plate shows the measurement effect. However, it can only be evaluated under a microscope at the end of the test. There is also disadvantage of strain