ILSCO connections matter

Engineering Handbook for Electrical Connectors

A brief summary of comparative properties of metals suitable for current carrying applications and required features of the connector follows.

Silver, Copper, Gold, Aluminum and Magnesium have comparable properties, for current carrying applications and required features of the connector. The above mentioned pure metals all contain relative electrical conductivity which can be defined by Percentage of Volume Conductivity. Silver has 108.3% Volume Conductivity. Copper contains 100% Volume Conductivity. Gold assumes 73.4% Volume Conductivity. Aluminum has 64.9% Volume Conductivity. Magnesium contains 38.0% Volume Conductivity.

The commercial use of copper and aluminum for electrical applications are obvious, in terms of economic justifications. The accelerated use of aluminum becomes even more obvious when realized that it requires twice the amount of copper by weight, to carry a specified amount of current. At the unit price per pound of prime metal it is readily seen why aluminum is increasing in electrical application.

As the next logical step, an examination of available alloys and forms of aluminum should be made to determine the optimum choice for the manufacture of electrical connectors.

Aluminum is available in a variety of suitable alloys and forms which allow for the optimum choice for the manufacture of electrical connectors. The following Aluminum Alloys are defined by Form, Typical Yield Strength, Minimum Yield Strength, Elongation, and Percent of Conductivity. 6061-T6, in the Extrusion Form, has a Typical Yield Strength of 40-45,000 psi, Minimum Yield Strength of 35,000 psi. Elongation of 12, and 40% Conductivity. 6063-T6, in the Extrusion Form, has a Typical Yield Strength 22,000 psi, Elongation of 3.5, and 39% Conductivity. 356-T6, in the Sand Cast Form, has a Typical Yield Strength of 24,000 psi, Minimum Yield Strength of 24,000 psi, Elongation of 3.5, and 39% Conductivity. AXS 679 (380A), in the Die Cast Form, has a Typical Yield Strength of 21,000 psi, Minimum Yield Strength 21,000 psi, Elongation of 3, and 25% Conductivity.

During the initial analysis of these materials, reference was made to the experience over many of the effect of stress on tensioned overhead conductors. It is well documented that in order to assure mechanical stability of these conductors, over long periods of time, it is necessary to design the line so that the maximum stress will not exceed 50% of the conductors rated breaking strength. In the case of aluminum conductors the alloy most commonly used is EC-H19 having a yield strength, will result in the conductor remaining mechanically stable throughout its life.

The method of testing used to confirm this premise is noted later.

Additional factors of design were recognized as necessary to achieve a stable and reliable connector.

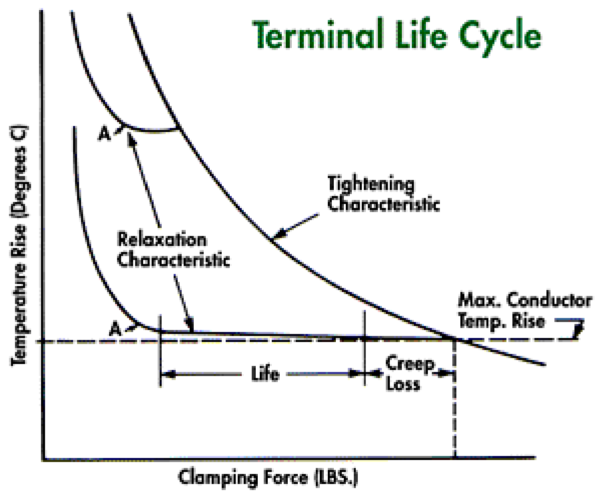
Requirements of aluminum connectors for use with aluminum or copper conductors.

1. Adequate strength of the connector to prevent creep loss in the connection from exceeding the creep loss of the conductor.
2. Strong enough clamping force (torque) to keep the connector operating temperature at a level below the operating temperature of the maximum size conductor.
3. High enough conductivity to provide adequate efficiency (minimum of 40%).

To illustrate the significance of these requirements, the *Terminal Life Cycle* Table presents an examination of terminal temperature in relation to clamping force. The horizontal dotted line indicates the temperature of the conductor at maximum rise. The tightening characteristic curve shows a lowering of terminal temperature rise with an increased clamping force. Terminal temperature, measured in degrees centigrade, is used in our illustration as a measure of connector resistance. As the tightening characteristic curve approaches the dotted conductor temperature line at the same current value, the connector and conductor resistance approximate each other.

The curves labeled Relaxation Characteristic, merely indicate the anticipated progression a connector would follow to failure, once clamping force has been reduced to a level where terminal resistance can no longer be maintained at a low level. Point A on each curve represents that point where resistance is sufficiently high to cause an elevated operating temperature of the connector which will then progress to ultimate connector failure.

Proceeding with the assumption that stress limitation is a most critical factor in connector design it was then necessary to select and test the alloy materials which evidence the most favorable conductivity/yield strength/economic factors. The initial selection of aluminum alloy 6061-T6 has long since been determined to be the best available material from which to fabricate connectors for use with both aluminum and copper conductors.



Before proceeding further a definition of terms used, to assure understanding of the basis for the conclusions reached later in the paper, are listed.

Physical Property of Aluminum

Tensile Strength
The maximum tensile load which a material is capable of withstanding under gradually and uniformly applied loading, divided by the original cross-sectional area in the minimum plane perpendicular to the direction of loading. Commonly the term is taken to mean the same as "ultimate tensile strength" or the less accurate "breaking strength".

Yield Strength
The stress at which material exhibits a specified permanent set. The value of set used for aluminum and its alloys is 0.002 inch per inch or 0.2%. For the aluminum alloys the yield strength in tension and compression are approximately the same.

Elongation
The increase in distance between two gage marks that results from stressing the specimen in tension to fracture.

The distance between gage mark measurements start at 2.000 before the applied load. When distance between gage marks measures 2.004, level of tensile load indicated on gage is recorded as material specimen's yield strength.

To record elongation, tensile loading is continually applied until specimen fractures, at which time two pieces are mated and distance between gage marks accurately measured. The resultant dimension divided by the original increment provides the value expressed in %, of the materials ability to stretch under load, or its elongation.

Elastic Limit
The stress value below which no permanent set or permanent deformation takes place; the highest stress which will permit return to original shape upon removal of force causing the stress.

Elasticity
The ability of a material to return to its original shape and size upon removal of a load below the elastic limit.

Creep
A precise unit of measure disclosing the increase in dimension of a unit specimen having a specified area = A, an applied force = W with resultant stress = W/A. The initial increment of measurement L, is effected by three factors resulting in amount of increase or creep, stress, time and temperature.

To determine and express the creep rate for a given specimen in terms of inches of creep, per inches of original gage length, per hour, the factors of stress and temperature must be maintained constant. A change in either or both, will result in a change in the creep rate.

Cold Flow
As compared to Creep, cold flow has no units of measure. The best description of cold flow relating to application within the electrical industry, is an excessively high rate of creep i.e. normal creep rate static load condition would be expressed in a fraction of an inch per inch of length. Cold flow, conversely if possible to measure it in definable terms, would be expressed in terms of inches of movement per inch of length. Cold flow then can be expressed as movement of appreciable magnitude occurring at a stress level in a very short length of time at an ambient temperature. Neither time or temperature are critical in assessing the effecting force of cold flow.

It is significant to realize that it is an absolute necessity to have cold flow of the conductor within a bolted connector to develop the desired low resistance contact, required for electrical/mechanical stability of the connection. So is it necessary to have cold flow of both the conductor and connector in the making of a compression connection. In these two instances a mechanical union of the two components is made by means of an externally applied force to assure both electrical and mechanical reliability. In the case of a soldered or welded connection this component union is made metallurgically.

Creep Loss
The unit of measurement, expressed in % of the initially applied mechanical force to a connection, divided by the resultant measured force after the unit has been subjected to controlled loadings of temperature and time. This value is relatively easy to determine for bolted connectors by accurately measuring applied torque before and after applying control factors of time and temperature. The resultant loss of torque is the creep loss experienced within the connection assembly.

It is difficult and inaccurate to project anticipated creep loss within a compression assembly since there is no way of effecting a measurement of the initially applied force and the resultant force remaining on the connection after the mechanical or hydraulic compression tool is removed from the connector.

The maximum desired creep loss in a connector/conductor assembly stated, is that portion of the total creep component represented by the creep component of the conductor alone.

This brings us to the threshold of the discussion of design parameters used by ILSCO in the manufacturer of aluminum connectors.

The Tolerable Creep Limits for Aluminum Connectors can be defined in terms of Stress Area, Initial psi and result in a percentage of Creep Loss after a one-hour heat run in an oven at 212° F. Aluminum 6061-T6 with a Stress Area of .332, has initially applied mechanical force of 11,500 psi and after a one-hour heat run in an oven at 212° F, has a 13.3% Creep Loss. Another section with a Stress Area of .249, at 15,400 psi, reaches 13.3% Creep Loss. The section with Stress Area of .166, at 23,100 psi, reaches 13.3% Creep Loss. The section with Stress Area of .132, at 29,100 psi, reaches 25% Creep Loss.

To best understand the importance of the function of creep components in a connection assembly, recall the definition of cold flow wherein it is stated that it is necessary to the formulation of an electrically/mechanically stable connection to have cold flow of the conductor. Since cold flow is by definition a high rate of creep and since creep occurs only where constant stress is applied; the connection will undergo creep movement as a result of load cycling. It is mandatory that the connector be so designed that all creep within the assembly occur in the conductor.

The determination of tolerable creep limits for aluminum connector design were established through the test described below.

This test established the maximum stress which can be imposed on an aluminum connector made from Alloy 6061-T6 as being 23,000 psi which is approximately 1/2 typical yield strength. The value of creep loss for the first three connectors were identical; 13.3% whereas the fourth exhibited a 25% creep loss. The explanation is simply that the loads applied to the section modules of each of the first three test connectors resulted in a stress level below the elastic limit of the material and thereby causing no creep movement in the connector. The conductor on the other hand must be physically moved, and this conductor movement resulted in a redistribution of strand displacement and resultant redistribution of load. The 13.3% creep loss therefore can be stated as being that movement occurring within the conductor.

The Fourth sample, however, evidenced in higher creep loss, resulting from creep in the conductor and the connector since the connector was stressed beyond its elastic limit and contributed to the total creep of the assembly.

The confirmation by actual test of this limitation of stress to 1/2 the materials yield strength has been utilized in the design of all connectors manufactured by ILSCO.

Preparation of wire

When an aluminum cable is installed, certain procedures should be followed to ensure a good connection.

1. The insulation should be stripped with a whittling motion to prevent the cable from being nicked.
2. The cable should then be cleaned with a wire brush. This removes the oxides from the surface of the conductor.
3. An oxide inhibitor (De-Ox) is recommended to be applied to aluminum conductor immediately prior to installation.
4. For mechanical connectors, the set screw should be tightened. After a few seconds, the set screw should be re-tightened to ensure a good connection. For compression connectors, the lug should be crimped around the conductor using the proper tool.

Instructional Information
Proper Installation of Electrical Connectors

Mechanical Connector Installation

1. Select proper size
2. Strip conductor, per installation instructions
3. Clean exposed wire
4. Apply De-Ox® oxide inhibiting compound
5. Insert wire into connector
6. One conductor per opening unless indicated
7. Tighten connector to recommended torque

Compression Connector Installation

1. Select proper size
2. Strip conductor, per installation instructions
3. Clean exposed wire
4. Insert Wire into connector - De-Ox® oxide inhibitor pre-loaded in connector
5. Compress connector per manufacturer recommendations