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SOLDERING SHEETS USING SOFT SOLDERS

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Abstract

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The paper contains strength tests results of joints soldered using lead and leadless soft solders. For tests lead solders types Pb60Sn40 and Sn60Pb40 and leadless soft solders types Sn95.5Ag3.8Cu0.7 and Sn96Ag4 were used. As basic materials steel sheet, zinc-coated steel sheet, copper sheet and brass sheet 100 x 20 x 1 mm was the test samples size. Always two sheets were cleaned and jointed together. For heating the propane-butane + air flame was used. Then the tested assemblies were loaded using the universal tensile-strength testing machine till to failure. At the tests the force needed for assemblies failure and failure type (in soldered joint, in basic material) were recorded. From measured data the solder strength was calculated. From the experiment results it follows that from the point of view of the soldered joints strength as well of the solder strength relatively small differences were found. At the same time it is evident that the joint strength and solder strength depend on soldered material type and on soldered joint lapping length. On the basis of carried out experiments it can be stated that the substitution of lead solders by leadless solders is possible without risk of soldered joints strength decrease.

soldered joints, leadless solders, laboratory tests, tensile lap-shear strength

Soldering technology belongs to the oldest methods of material jointing using heat. It has been used already 3500 years ago in Old Egypt. In the territory of Czech Republic soldering is documented by archaeological discovery from the era of Great Moravia Empire (second half of the 9th century). It was used at jewels making. But development of soldering industrial use is dated back to less far past. At the beginning of twentieth century soldering came into use for jointing of thin metallic materials. Its next development is closely connected with the development of automobile, electrical and light industry. Today it is luxuriantly used not only for single-part production but in serial and mass production, too. Its optimal use is e.g. at products of general and precision engineering, in electrical, chemical, light and aircraft industry, in cosmonautics, at production of imitation jewelry and in other fields. Properties of soldered joints are specific, e.g. joints can be gas proof, waterproof, electric conductible, corrosion proof etc. Joints are tough both at static and dynamic stress.

In the same way as other methods of jointing the soldering technology is of advantages and disadvantages and therefore of its optimal application fields. Among advantages can be enumerated less energy consumption, higher operating speed, high economy, higher labor productivity, possibility of mechanization and automation, possibility of almost all metallic materials jointing regardless of their size and thickness, only low stress in the joint, lower effect on jointed materials properties and at last a fair visual appearance. Disadvantages are e.g. lower strength and heat resistance (Blaščík *et al.*, 1987; Ruža, 1988; Mahmudi and Eslami, 2011).

However in the field of metallic materials jointing the soldering technology is not dominant, but it suitably completes other methods, e.g. bonding (Kašpar, 2005; Műller, 2006; Brožek, 2013a; Brožek, 2014) or welding (Blaščík *et al.*, 1987; Brožek, 2007).

At soldering filler materials, so-called solders of various chemical composition and properties, are used. Most often solders are classified according to their working temperature as soft solders (upper melting point < 450 °C) and hard solders (upper melting point > 450 °C).

Compared with hard solders the working temperatures of soft solders are lower and mechanical properties are lower, too. Therefore they are used for joints which are not so much stressed by strength and heat. From the chemical composition point of view it is a case of tin solders (alloys Sn-Pb with various ratio of both metals) and special solders. Except Sn and Pb these solders contain other metals, most often Cd, Zn, Ag, Cu, Sb, Bi, In. Hard solders are made as alloys on the Cu, Al, Mg, Ni, Fe, Ag and noble metals basis (Nippes, 1983; Wood and Nimmo, 1994; Glazer, 1995; Roberts, 2004; Abel, 2005).

Relatively new classes of soft solders are so-called leadless solders, in Czech Republic made from twentieth years of the last century (Soft solders). Their importance has increased after the 1. July 2006 when the Directive of European Union (EU-WEEE, Waste from Electrical and Electronic Equipment) has come into operation (Directive 2002/95/ES, 2003; Directive 2002/96/ES, 2003). It has restricted the use of lead solders in electrical industry. The elimination of lead from production of light, telecommunication etc. industry will contribute to the human environment betterment. Lead contained in Sn-Pb solders can at unsuitable handling with scrapped electrical and electronic equipments (all equipments which use electric energy, e.g. big and small electrical appliances, computers, monitors, television and radio receivers, toys) contaminate soil and consequently the whole nutritious chain. Leadless soldering influences doubtless commercial effect, when producers of "green products" can expect higher saleability of their products.

Soft leadless solders are alloys of Sn with addition of Ag, Cu, Bi, In and other chemical elements. From the material point of view they are binary alloys (e.g. Sn-Ag, Sn-Cu, Sn-Sb, Sn-Zn, Sn-Bi), ternary alloys (Sn-Ag-Cu, Sn-Ag-Bi, Sn-Sb-Cu, Sn-Zn-In, Sn-Zn-Bi etc.), quaternary alloys (e.g. Sn-Ag-Cu-Sb, Sn-Ag-Cu-In, Sn-Zn-Bi-X etc.), eventually even more complicated ones (Manko, 1979; Miric and Grusd, 1998; Roberts, 2004; Saganuma, 2011; Abel, 2005; Abtew, M. and Selvaduray, G, 2010; Měkké pájky, 2013).

MATERIALS AND METHODS

The aim of experiments, whose results are published in this paper, was to judge strength of joints soldered using soft lead and leadless solders. For tests two soft lead solders (types Pb60Sn40 and Sn60Pb40) and two soft leadless solders (types Sn95.5Ag3.8Cu0.7 and Sn96Ag4) were chosen.

The published results are the part of the study carried out over a long period in our department with the aim to evaluate the properties of joints soldered using lead and leadless solders (Brožek and Nováková, 2009; Chlustinová, 2009; Kuchař, 2011; Brožek, 2013b).

As jointed material steel sheet (tensile strength R_m = 327 ± 5 MPa), zinc-coated steel sheet (R_m = 357 ± 2 MPa), copper sheet (R_m = 241 ± 1 MPa) and brass sheet (R_m = 364 ± 1 MPa), always of 1.0 mm thickness, were used. From this semi-products test samples of dimensions 100 × 20 mm were sheared (Fig. 1). Two samples were always put together with different lap (length l = about 2.5, 5.0, 7.5, 10.0, 15.0 and 20.0 mm), cleaned using soldering flux and soldered. Soldering was carried out using the propane-butane + air flame.

Real dimensions of all tested assemblies soldered surfaces were determined – width *b* (mm) and lapping length *l* (mm). Next the assemblies were loaded till to the failure. At each test the force *F* (N) needed for the joint failure and the failure type (failure of the soldered joint, failure of the sample basic material) were noted.

From these values the soldered joint surface *S* (mm^2) was calculated

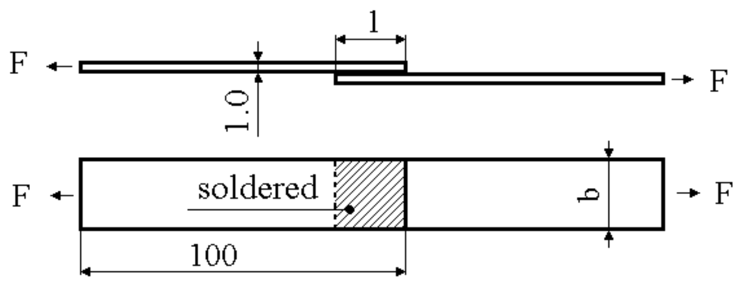
$$S = b \times l, \tag{1}$$

where:
S .... Soldered joint surface (mm^2),
b..... Soldered width (mm),
l...... Soldered lapping length (mm).

The tensile lap-shear strength τ (MPa) of the soldered assembly was calculated using the equation

$$\tau = \frac{F}{S}, \tag{2}$$

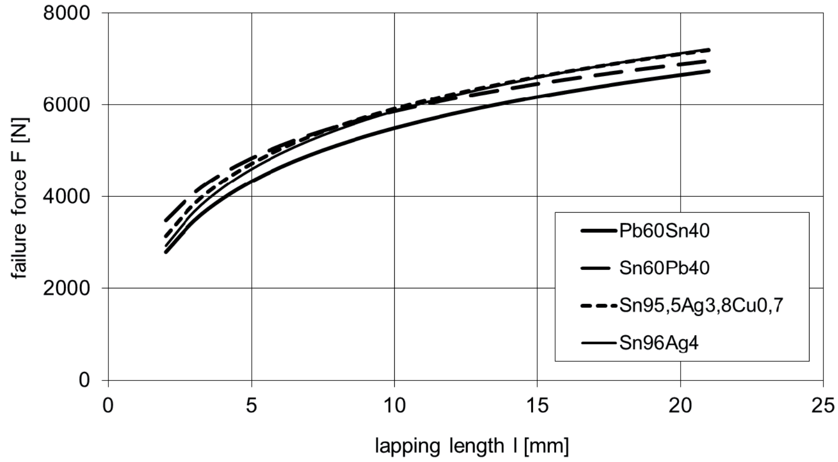
where:
τ..... Tensile lap-shear strength (MPa),
F .... Failure force (N),
S .... Soldered joint surface (mm^2).



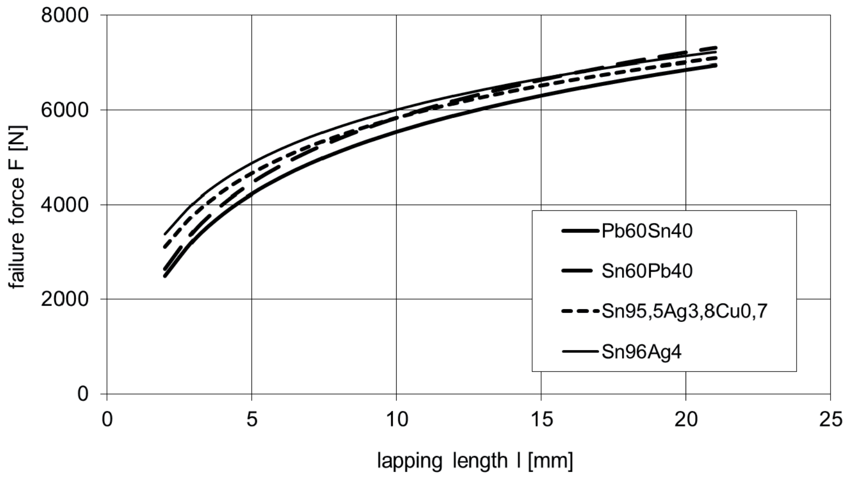
1: *Dimensions of the test assembly*

RESULTS AND DISCUSSION

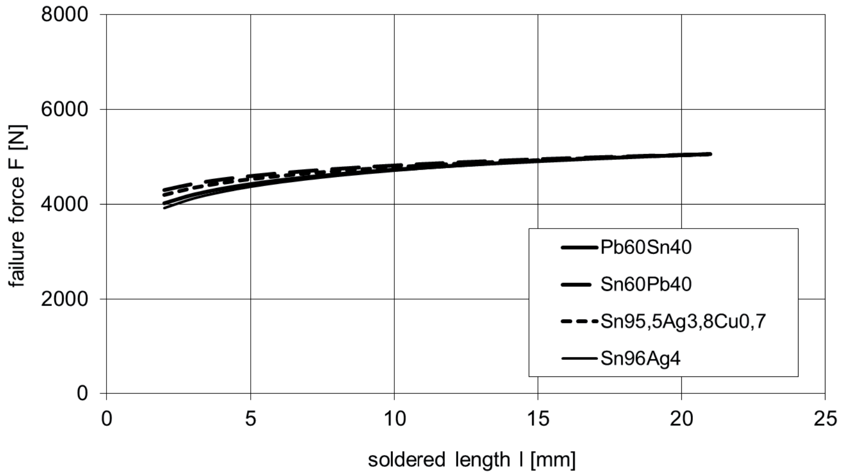
Relations between the force needed for the joint failure and the soldered length are presented in Figs. 2–5. The results of samples from steel are shown in Fig. 2, from zinc-coated steel in Fig. 3, from copper in Fig. 4 and from brass in Fig. 5.



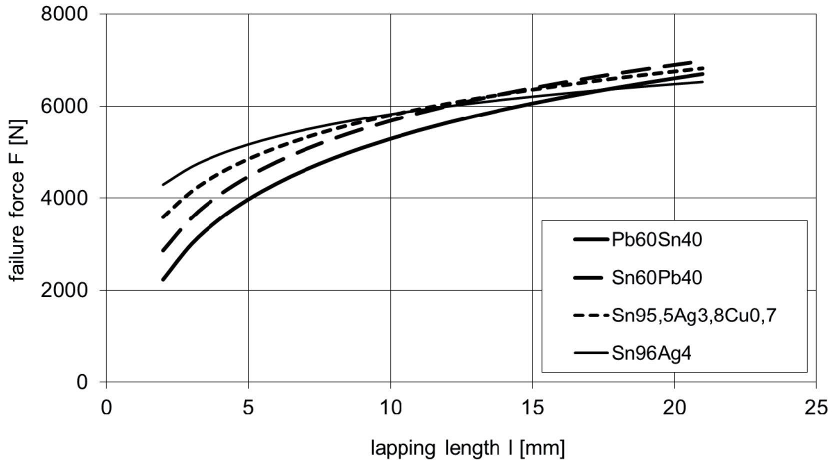
2: *Relation between force needed for soldered joint failure and lapping length (steel)*



3: *Relation between force needed for soldered joint failure and lapping length (zinc-coated steel)*



4: *Relation between force needed for soldered joint failure and lapping length (copper)*



5: *Relation between force needed for soldered joint failure and lapping length (brass)*

It is evident that the course of all tests is very similar. The force needed for the failure increases at first very rapidly; afterwards its increase is slow (Figs. 2–5). After reaching of soldered surface certain size the failure occurs in the basic material and the increase of soldered surface is purposeless.

At soldering of samples made from steel sheet (Fig. 2) the lowest strength was measured at the use of the lead solder Pb60Sn40 of the lower lead content. At other tested solders similar values were measured. At lapping length under about 10 mm the highest joint strength was determined using the lead solder Sn60Pb40. At the lapping length over about 10 mm the joints soldered using both leadless solders were stronger. Nevertheless the determined differences are relatively small.

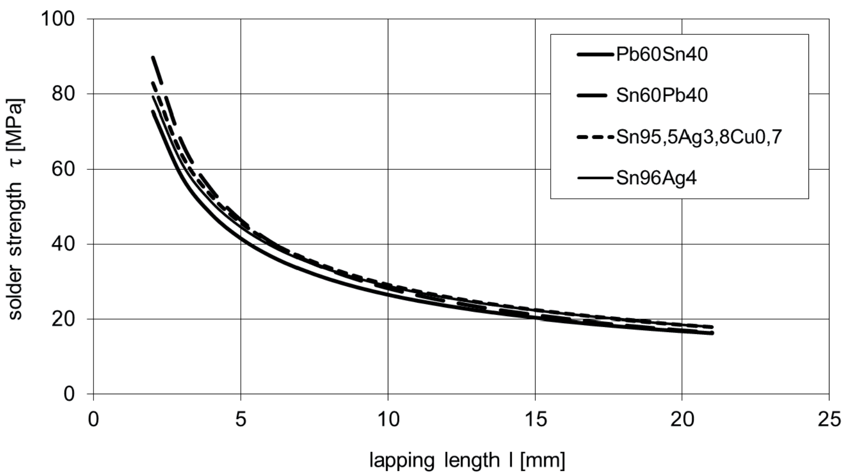
At soldering of samples made from zinc-coated steel sheet (Fig. 3) the highest strength was determined at the use of the leadless solder Sn96Ag4. The lowest strength was measured at joints soldered using the lead solder Pb60Sn40. Also in this case the differences between single solders are relatively small.

At soldering of samples made from copper sheet (Fig. 4) the dependences were quite different compared with soldering of other materials. All four curves almost coincided, especially at the lapping length more than 10 mm, where in all cases the failure of the sample material occurred. Above all it was caused by the lower strength of copper sheet compared with strength of other tested materials.

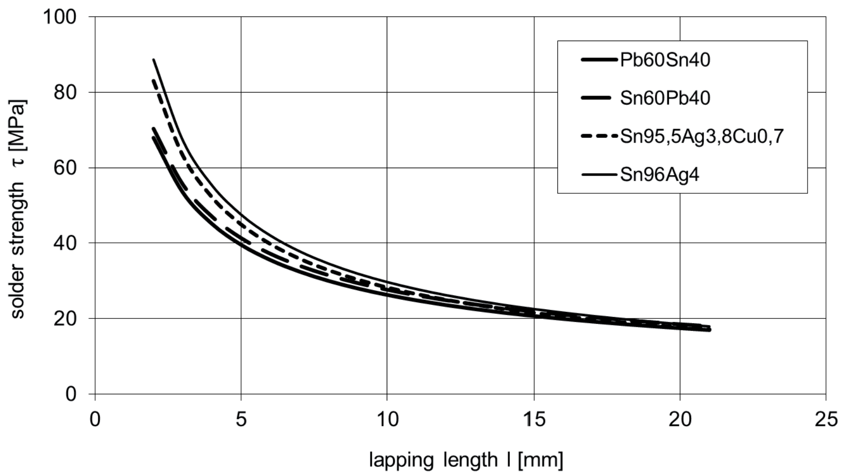
At soldering of samples made from brass sheet (Fig. 5) the significant differences were determined at the forces needed for the joint failure at the lower lapping lengths. Higher values were determined at joints soldered using both leadless solders. At bigger lapping lengths the differences were small.

The relation between failure force and lapping length (Figs. 2–5) is in all cases of rising tendency, which can be described with a relatively high accuracy by the logarithmic function (Tabs. I and II).

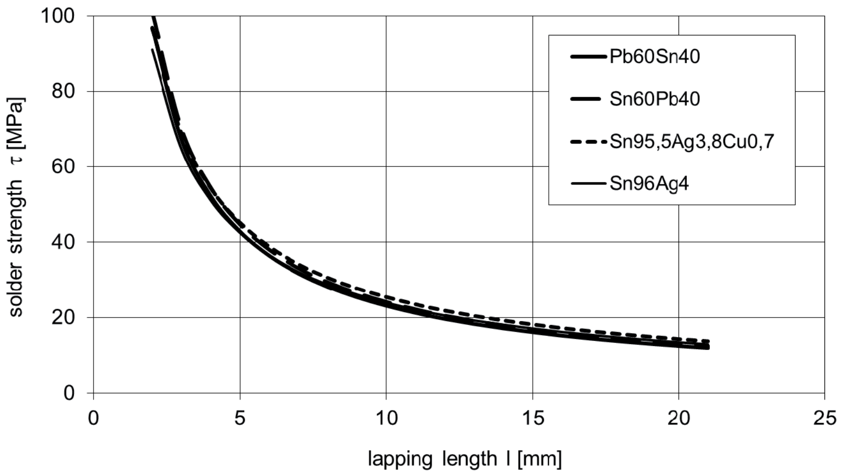
From the results of all tests presented in Figs. 2–5 only these ones were selected for next evaluation which failed in the soldered surface (not in the basic material). Relations between solder strength and lapping length are presented in Figs. 6–9.



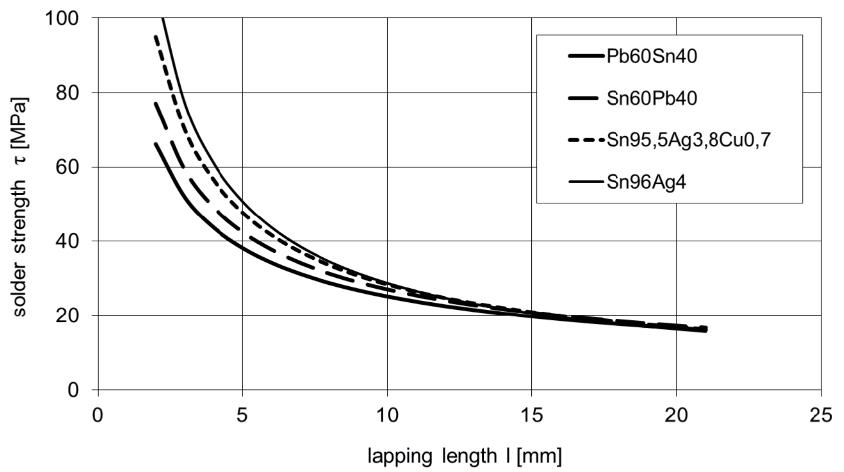
6: *Relation between solder strength and lapping length (steel)*



7: *Relation between solder strength and lapping length (zinc-coated steel)*



8: *Relation between solder strength and lapping length (copper)*



9: *Relation between solder strength and lapping length (brass)*

Fig. 6 shows results of the steel samples, Fig. 7 of the zinc-coated samples, Fig. 8 of the copper samples and Fig. 9 of the brass samples.

From the results (Figs. 6–9) it is evident that at all tested solders (lead solders and leadless solders) the course of the relations is very similar. The solder strength decreases relatively rapidly.

At soldering of samples made from steel sheet (Fig. 6) the lowest strength was determined at the solder type Pb60Sn40 of the lower Sn content. The highest strength was determined at the solder type Sn60Pb40. The strength of both tested leadless solders was very similar. From the view of praxis the differences are insignificant.

At soldering of samples made from zinc-coated steel sheet (Fig. 7) the highest strength was determined at the leadless solder type Sn96Ag4. Only mildly lower strength was measured at other tested solders types Sn95.5Ag3.8Cu0.7, Sn60Pb40 and Pb60Sn40.

At soldering of samples made from copper sheet (Fig. 8) it was found that strength of all tested solders is almost identical. As it is evident from Fig. 8 the dependences on the lapping length practically coincide.

At soldering of samples made from brass sheet (Fig. 9) it was found that the higher strength of the soldered joint was reached at the use of leadless solders.

Results of all tested solders are similar – trend of the relations is decreasing. It is possible to express the relations by functions presented in Tabs. I–IV.

At the same time the known fact was confirmed that the lapping length of the one-sided lapped joint should be "adequate". No doubt that by the lapping length increase up to a certain value the force needed for the joint failure increases (Figs. 2–5, Tabs. I–IV) but at the same time the solder strength decreases (Figs. 6–9, Tabs. I–IV). In this way the force acts aside the axis and the additional bending moment arises. At the lapping borders this moment evokes the additional spalling stress.

CONCLUSIONS

The paper contents test results of soldered joints using test samples. Samples of size 100 × 20 mm were sheared from steel sheet, zinc-coated steel sheet, copper sheet and brass sheet, always of 1 mm thickness. Test assemblies for strength tests were prepared by soldering of two specimens. Soldering was carried out using the propane-butane + air

I: *Test results (steel sheet)*

Solder type	Equation of the relationship F – l	Coefficient R^2	Equation of the relationship τ – l	Coefficient R^2
Pb60Sn40	F = 1674.8.ln(l) + 1641.6	0.98	$\tau = 118.10.l^{-0.65}$	0.99
Sn60Pb40	F = 1477.0.ln(l) + 2464.7	0.94	$\tau = 147.78.l^{-0.72}$	0.99
Sn95,5Ag3,8Cu0,7	F = 1722.3.ln(l) + 1953.3	0.97	$\tau = 130.03.l^{-0.65}$	0.99
Sn96Ag4	F = 1819.7.ln(l) + 1677.5	0.89	$\tau = 122.69.l^{-0.63}$	0.95

II: *Test results (steel zinc-coated sheet)*

Solder type	Equation of the relationship F – l	Coefficient R^2	Equation of the relationship σ – l	Coefficient R^2
Pb60Sn40	F = 1894.1.ln(l) + 1176.1	0.93	$\tau = 102.23.l^{-0.59}$	0.93
Sn60Pb40	F = 1985.8.ln(l) + 1262.2	0.96	$\tau = 105.13.l^{-0.58}$	0.96
Sn95,5Ag3,8Cu0,7	F = 1693.8.ln(l) + 1933.2	0.96	$\tau = 132.09.l^{-0.67}$	0.99
Sn96Ag4	F = 1632.9.ln(l) + 2245.6	0.95	$\tau = 142.04.l^{-0.68}$	0.98

III: *Test results (copper sheet)*

Solder type	Equation of the relationship F – l	Coefficient R^2	Equation of the relationship τ – l	Coefficient R^2
Pb60Sn40	F = 440.3.ln(l) + 3498.1	0.85	$\tau = 179.60.l^{-0.89}$	1.00
Sn60Pb40	F = 322.3.ln(l) + 4079.3	0.79	$\tau = 187.41.l^{-0.89}$	1.00
Sn95,5Ag3,8Cu0,7	F = 363.5.ln(l) + 3948.7	0.75	$\tau = 171.97.l^{-0.83}$	1.00
Sn96Ag4	F = 489.9.ln(l) + 3584.6	0,79	$\tau = 161.74.l^{-0.83}$	0.99

IV: *Test results (brass sheet)*

Solder type	Equation of the relationship F – l	Coefficient R^2	Equation of the relationship τ – l	Coefficient R^2
Pb60Sn40	F = 1898.8.ln(l) + 912.6	0.96	$\tau = 100.25.l^{-0.60}$	0.97
Sn60Pb40	F = 1752.0.ln(l) + 1642.5	0.97	$\tau = 120.94.l^{-0.65}$	0.99
Sn95,5Ag3,8Cu0,7	F = 1374.5.ln(l) + 2631.7	0.89	$\tau = 159.67.l^{-0.75}$	0.99
Sn96Ag4	F = 949.6.ln(l) + 3631.1	0.94	$\tau = 189.92.l^{-0.82}$	1.00

flame. For soldering two types of lead solders (Pb60Sn40 and Sn60Pb40) and two types of leadless solders (Sn95.5Ag3.8Cu0.7 and Sn96Ag4) were used. Soldered samples were loaded using the universal tensile-strength testing machine till to failure. The failure force was read. Then the strength of used solders was calculated.

From results of carried out tests it follows that between four tested solders from the point of view of soldered joints strength as well of solder strength only small differences exist. At the same time it is evident that the joint strength depends on the soldered material and also on the lapping length.

On the basis of carried out tests it is possible to note that the substitution of lead solders by leadless solders is possible without danger of soldered joints strength decrease.

SUMMARY

Relatively new classes of soft solders are so-called leadless solders, in Czech Republic made from twentieth years of the last century (Soft solders). Their importance has increased after the 1. July 2006 when the Directive of European Union (EU-WEEE, Waste from Electrical and Electronic Equipment) has come into operation (Directive 2002/95/ES, 2003; Directive 2002/96/ES, 2003). It has restricted the use of lead solders in electrical industry. The elimination of lead from production of light, telecommunication etc. industry will contribute to the human environment betterment. The paper contains strength tests results of joints soldered using lead and leadless soft solders. For tests lead solders types Pb60Sn40 and Sn60Pb40 and leadless soft solders types Sn95.5Ag3.8Cu0.7 and Sn96Ag4 were used. As basic materials steel sheet, zinc-coated steel sheet, copper sheet and brass sheet 100 × 20 × 1 mm was the test samples size. Always two sheets were cleaned and jointed together. For heating the propane-butane + air flame was used. Then the tested assemblies were loaded using the universal tensile-strength testing machine till to failure. At the tests the force needed for assemblies failure and failure type (in soldered joint, in basic material) were recorded. The relation between failure force and lapping length is in all cases of rising tendency, which can be described with a relatively high accuracy by the logarithmic function. From measured data the solder strength was calculated. From the results it is evident that at all tested solders (lead solders and leadless solders) the course of the relations is very similar. The solder strength decreases relatively rapidly. From the experiment results it follows that from the point of view of the soldered joints strength as well of the solder strength relatively small differences were found. At the same time it is evident that the joint strength and solder strength depend on soldered material type and on soldered joint lapping length. On the basis of carried out experiments it can be stated that the substitution of lead solders by leadless solders is possible without risk of soldered joints strength decrease.

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