Soldering steel sheets using soft solders

M. Brožek

Department of Material Science and Manufacturing Technology, Faculty of Engineering, Czech University of Life Sciences Prague, Prague, Czech Republic

Abstract

Brožek M., 2013. **Soldering steel sheets using soft solders**. Res. Agr. Eng., *59*: 141–146.

The paper contains strength tests results of joints soldered using lead and leadless soft solders. For tests lead solders types Sn63Pb37, Sn60Pb40, Pb60Sn40 and Pb48Sn32Bi and leadless soft solders types Sn96Ag4, Sn99Cu1, Sn70Zn30 and Sn96Ag3Cu1 were used. As basic joint material steel sheet of 1.0 mm thickness and zinc-coated steel sheet of 1.0 mm thickness were used. The size of test specimen was 100 × 20 mm. Two sheets were always cleaned and jointed together. For heating the propane-butane plus air flame was used. The tested assemblies were loaded using the universal tensile-strength testing machine until their failure. At the tests the force needed for assemblies' failure and failure type (in the soldered joint, in the basic material) was recorded and the solder strength was calculated from the measured data. The test results show that for soldering of steel sheets as well of zinc-coated steel sheets of 1.0 mm thickness the joints soldered using the lead soft solder type Sn63Pb37 and the leadless soft solder type Sn96Ag4 were of the highest strength.

Keywords: soldered joints; leadless solders; laboratory tests

Soldering technology belongs among the oldest methods of material jointing using heat. It had been used already 3,500 years ago in Ancient Egypt. In the territory of the Czech Republic soldering is documented by archaeological discoveries from the era of the Great Moravia (second half of the 9th century). It was used for making jewels. But the development of soldering in industrial use is dated back to nearer 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 amply used not only for single-part production but in serial and mass production, too. Its optimal use is e.g. at products of precision and general engineering, in electrical, chemical, light and aircraft industry, in cosmonautics, at production of imitation jewellery and in other fields. Properties of soldered joints are specific, e.g. joints can be gas proof, waterproof, electrically conductive, corrosion proof etc. Joints are tough both at static and dynamic stress (Ruža 1988).

In the same way as other methods of jointing the soldering technology has its advantages and disadvantages and therefore has its optimal application fields. Among advantages can be enumerated lower energy consumption, higher operating speed, high economy, higher labour 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.

As soldering filler materials are used so-called solders of various chemical composition and properties. Most often solders are classified according to their working temperature as soft solders (up-

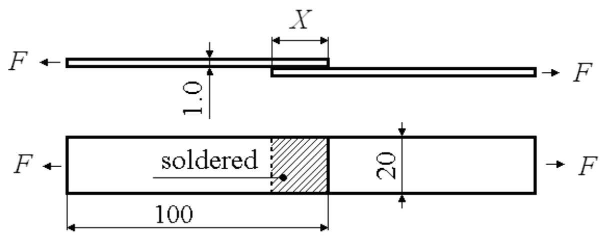

Fig. 1. Dimensions of the test assembly
X – overlapping length; F – force needed for soldered joint failure

per melting point < 450°C) and hard solders (upper melting point > 450°C) (Blaščík et al. 1987).

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 chemical composition point of view they are 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.

Relatively new classes of soft solders are so-called leadless solders; in the Czech Republic they have been made from the 1920's. Their importance increased after the July 1, 2006 when the Directive of the European Union (Directive 2002/95/EC, Directive 2002/96/EC) came into force that restricted the use of lead solders in electrical industry. The elimination of lead from light, telecommunication etc. industry would contribute to the betterment of the human environment. Lead contained in Sn-Pb solders can contaminate soil and consequently the whole nutritious chain at unsuitable handling with scrapped electrical and electronic equipment (all equipment which use electric energy, e.g. big and small electrical appliances, computers, monitors, television and radio receivers, toys). Leadless soldering influences doubtless commercial effect, when producers of "green products" can expect higher negotiability of their products (Directive 2002/95/EC, Directive 2002/96/EC).

Soft leadless solders are alloys of Sn with addition of Ag, Cu, Bi, In, and other chemical elements. From 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), or even more complicated ones (Nippes 1983; Weman 2003; Roberts 2004; Abel, Cimburek 2005; Anonymous 2009).

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 four soft lead solders (types Sn63Pb37, Sn60Pb40, Pb60Sn40 and Pb48Sn32Bi) and four soft leadless solders (types Sn96Ag4, Sn99Cu1, Sn70Zn30 and Sn96Ag3Cu1) were chosen (all produced by Kovohutě Příbram, Příbram, Czech Republic).

As jointed material iron steel sheet of 1.0 mm thickness and zinc-coated steel sheet of 1.0 mm thickness were used. From these semi-products, test samples of dimensions 100 × 20 mm were sheared. Two samples were always put together with different lap (X = about 2.5, 5.0, 7.5, 10.0, 12.5, and 15.0 mm), cleaned using soldering flux and soldered (Fig. 1). Soldering was carried out using the propane-butane + air flame.

Real dimensions of all tested assemblies' soldered surfaces were determined. Next the assemblies were loaded until their failure. At each test the force needed for the joint failure and the failure type (failure of the soldered joint, failure of the sample basic material) were noted (Brožek, Nováková 2008, 2009).

RESULTS AND DISCUSSION

Relations between the force needed for the joint failure and the lapping length are presented in Figs 2 and 3. Fig. 2a presents the results of specimens from zinc-coated steel sheets soldered using lead solders, Fig. 2b shows the results of specimens from zinc-coated steel sheets soldered using leadless solders, Fig. 3a presents the results of specimens from steel sheets soldered using lead solders and Fig. 3b presents the results of specimens from steel sheets soldered using leadless solders.

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 (Fig 2). After reaching a certain size of soldered surface the failure occurs in the basic material and the increase of soldered surface is purposeless.

At soldered specimens made from zinc-coated steel sheet using lead solders (Fig. 2a) the high-

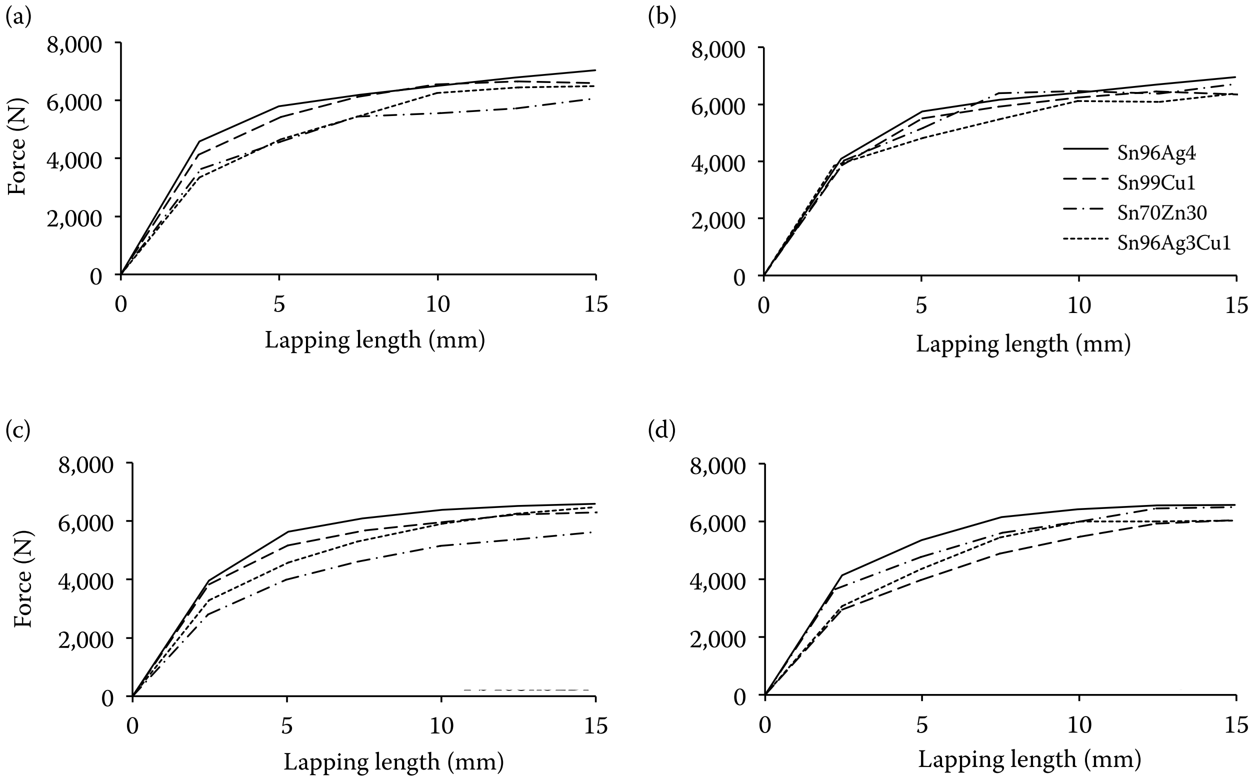

Fig. 2. Relation between force needed for soldered joint failure and lapping length: (a) zinc-coated steel, lead solders; (b) zinc-coated steel, leadless solders; (c) steel, lead solders and (d) steel, leadless solders

est strength was measured at eutectic solder type Sn63Pb37. Mildly lower strength was measured at solder type Sn60Pb40, even lower strength value was measured at solder type Pb60Sn40 and the lowest value at solder type Pb48Sn32Bi. Similar results were determined at specimens from steel sheet soldered using lead solders (Fig. 3c). Yet, from the comparison of results presented in Figs 2a and 2c it follows that at specimens made from steel sheet the determined strength values were slightly lower than at specimens made from zinc-coated steel sheet. At the same time it is possible to say that between the test results of specimens made from zinc-coated steel sheet using leadless solders (Fig. 2b) smaller differences exist than at lead solders (Fig. 2a).

From specimens made from zinc-coated steel sheets using leadless solders (Fig. 2b) the highest strength was measured at solder type Sn96Ag4. Slightly lower strength was determined at joints made using solders types Sn99Cu1 and Sn70Zn30. The lowest strength was determined at joints made using solder type Sn96Ag3Cu1. Very similar results were determined at specimens made from steel sheets soldered using leadless solders (Fig. 2d). The strength of soldered joints decreased in order of used solder types Sn96Ag4, Sn99Cu1, Sn70Zn30 and Sn96Ag3Cu1.

The relation between failure force and lapping length (Fig. 2) is in all cases of rising tendency, which can be described with a relatively high accuracy by the logarithmic function (Tables 1 and 2).

From the results of all tests presented in Figs 2 and 3 only those 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 Fig. 3. Fig. 4a presents the results of specimens from zinc-coated steel soldered using lead solders, Fig. 3b the results of specimens from zinc-coated steel soldered using leadless solders, Fig. 3c the results of specimens from steel soldered using lead solders and Fig. 3d the results of specimens from steel soldered using leadless solders.

From the results (Fig. 3) it is evident that at all tested solders (lead solders and leadless solders) the relation course is very similar. The solder strength decreases relatively rapidly.

Table 1. Test results (steel zinc-coated sheet)

Solder type	Relationship $F - X$	R^2	Relationship $\sigma - X$	R^2
Sn63Pb37	F = 1,317.7 × ln(l) + 3,498.1	0.96	$\sigma = 191.6 \times l^{-0.770}$	0.99
Sn60Pb40	F = 1,444.2 × ln(l) + 3,008.4	0.93	$\sigma = 169.7 \times l^{-0.731}$	0.99
Pb60Sn40	F = 1,856.1 × ln(l) + 1,704.0	0.93	$\sigma = 121.2 \times l^{-0.612}$	0.96
Pb48Sn32Bi	F = 1,340.9 × ln(l) + 2,463.8	0.86	$\sigma = 143.4 \times l^{-0.716}$	0.97
Sn96Ag4	F = 1,504.3 × ln(l) + 2,990.4	0.88	$\sigma = 168.6 \times l^{-0.720}$	0.97
Sn99Cu1	F = 1,399.2 × ln(l) + 2,911.9	0.86	$\sigma = 162.1 \times l^{-0.725}$	0.97
Sn70Zn30	F = 1,529.0 × ln(l) + 2,778.1	0.84	$\sigma = 159.8 \times l^{-0.708}$	0.96
Sn96Ag3Cu1	F = 1,364.9 × ln(l) + 2,736.0	0.89	$\sigma = 156.2 \times l^{-0.728}$	0.99

F – force needed for soldered joint failure; X – overlapping length; σ – solder strength; R^2 – coefficient of determination

At soldering of specimens made from zinc-coated steel sheet using lead solders (Fig. 3a) the highest solder strength was determined at the use of eutectic solder type Sn63Pb37. Slightly lower strength was determined at solder type Sn60Pb40. Solders types Pb60Sn40 and Pb48Sn32Bi were approximately of the same strength. Very similar results of solders types Sn63Pb37 and Sn60Pb40 were determined at soldering of specimens made from steel sheet using lead solders (Fig. 3c). But at this material the considerable strength differences were determined at solders types Pb60Sn40 and Pb48Sn-32Bi. From the comparison of results presented in Fig. 3 it follows that at all solders the determined strength results of soldered steel sheets are slightly lower than of soldered zinc-coated steel sheets.

At the specimens made from zinc-coated steel sheet soldered using leadless solders (Fig. 3b) the highest solder strength was determined at the use of solder type Sn96Ag4. Slightly lower strength was measured at other tested solders types Sn99Cu1, Sn70Zn30 and Sn96Ag3Cu1. On the contrary relatively different results were determined at specimens made from steel sheet using leadless solders (Fig. 3d). The solder strength decreased in order of used solders types Sn96Ag4, Sn96Ag3Cu1, Sn-70Zn30 and Sn99Cu1.

Results of all tested solders are similar – trend of the relations is decreasing. It is possible to express the relations by functions presented in Tables 1 and 2.

At the same time the known fact was confirmed that the lapping length of the one-sided lapped joint should be "suitable". No doubt that by the lapping length increase up to a certain value the force needed for the joint failure increases (Fig. 2; Tables 1 and 2) but at the same time the solder strength decreases (Fig. 3; Tables 1 and 2). In this way the force acts aside the axis and the additional bending mo-

Table 2. Test results (steel sheet)

Solder type	Relationship $F - X$	R^2	Relationship $\sigma - X$	R^2
Sn63Pb37	F = 1,437.1 × ln(l) + 2,974.2	0.90	$\sigma = 165.5 \times l^{-0.723}$	0.97
Sn60Pb40	F = 1,379.2 × ln(l) + 2,749.4	0.96	$\sigma = 156.6 \times l^{-0.725}$	0.99
Pb60Sn40	F = 1,807.4 × ln(l) + 1,672.9	0.98	$\sigma = 120.3 \times l^{-0.619}$	0.99
Pb48Sn32Bi	F = 1,569.1 × ln(l) + 1,450.7	0.98	$\sigma = 103.6 \times l^{-0.616}$	0.99
Sn96Ag4	F = 1,459.8 × ln(l) + 2,969.9	0.96	$\sigma = 168.2 \times l^{-0.726}$	0.99
Sn99Cu1	F = 1,809.1 × ln(l) + 1,247.8	0.98	$\sigma = 102.7 \times l^{-0.584}$	0.99
Sn70Zn30	F = 1,760.2 × ln(l) + 1,619.2	0.91	$\sigma = 112.7 \times l^{-0.603}$	0.94
Sn96Ag3Cu1	F = 1,559.2 × ln(l) + 2,397.0	0.97	$\sigma = 144.8 \times l^{-0.687}$	0.99

F – force needed for soldered joint failure; X – overlapping length; σ – solder strength; R^2 – coefficient of determination

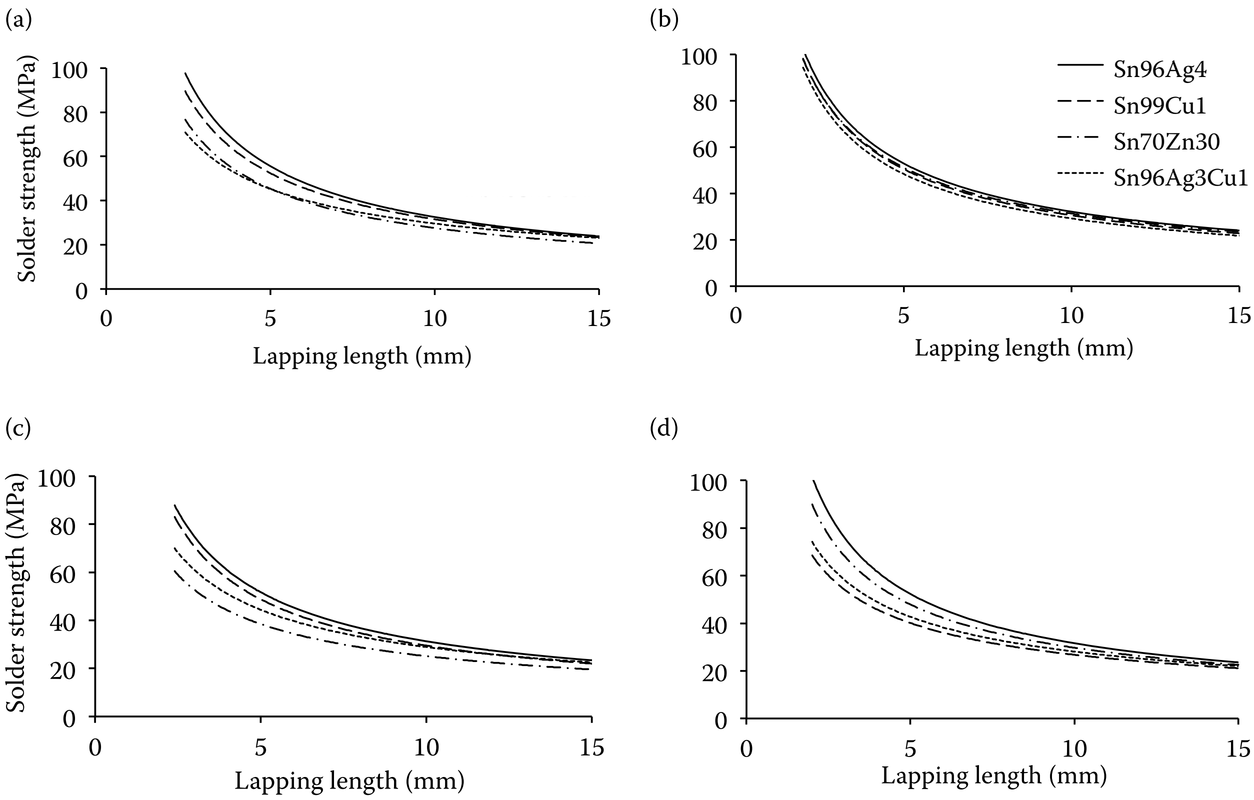

Fig. 3. Relation between solder strength and lapping length: (a) zinc-coated steel, lead solders; (b) zinc-coated steel, leadless solders; (c) steel, lead solders and (d) steel leadless solders

ment arises. At the overlapping borders this moment evokes the additional spalling stress.

CONCLUSIONS

The paper contents test results of soldered joints using test specimens. Specimens of size 100 × 20 mm were sheared from zinc-coated steel sheet and from steel sheet of 1.0 mm thickness. Test assemblies for strength tests were prepared by soldering of two specimens. Soldering was carried out using the propane-butane + air flame. For soldering, four types of lead solders (Sn63Pb37, Sn60Pb40, Pb60Sn40 and Pb48Sn32Bi) and four types of leadless solders (Sn96Ag4, Sn99Cu1, Sn70Zn30 and Sn96Ag3Cu1) were used. Soldered specimens 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.

The results of tests carried out show that between eight tested solders from the point of view of soldered joints strength as well as of solder strength only small differences exist. It is also possible to note that the substitution of lead solders by leadless solders is possible without danger of soldered joints strength decrease.

References

Abel M., Cimburek V., 2005. Bezolovnaté pájení v legislativě i praxi. [Lead-free Soldering in Legislature and Practice.] Pardubice, ABETEC: 179.

Anonymous, 2009. Měkké pájky. [Soft solders.] Available at http://www.kovopb.cz/userdata/pages/12/dp-solders.pdf (accessed January 29, 2012).

Blaščík F. et al., 1987. Technológia tvárnenia, zlievárenstva a zvárania. [Technology of Forming, Founding and Welding.] Bratislava, ALFA: 832.

Brožek M., Nováková A., 2008. Strength evaluation of soldered joints using lead and leadless solders. In: Material Science and Manufacturing Technology. Prague, Czech University of Life Sciences Prague: 35–39.

Brožek M., Nováková A., 2009. Soldering of steel using soft solders. In: Engineering for Rural Development. Jelgava, Latvia University of Agriculture: 315–318.

Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE) – Joint declaration of the European Parliament, the Council and the Commission relating to Article 9.

Nippes E.F., 1983. Metals Handbook. Vol. 6., Welding, Brazing, and Soldering. Metal Park, ASM Intenational: 1152.

Roberts P., 2004. Industrial Brazing Practice. Boca Raton, CRC Press: 383.

Ruža V., 1988. Pájení. [Soldering.] Prague, SNTL: 456.

Weman K., 2003. Welding Processes Handbook. Cambridge, Woodhead Publishing: 193.

Received for publication February 10, 2012
Accepted after corrections September 4, 2012

Corresponding author:

Prof. Ing. Milan Brožek, CSc., Czech University of Life Sciences Prague, Faculty of Engineering, Department of Material Science and Manufacturing Technology, Kamýcká 129, 165 21 Prague-Suchdol, Czech Republic
phone: + 420 224 383 265, fax: + 420 234 381 828, e-mail: brozek@tf.czu.cz