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Investigation of Mechanical Properties of Friction Stir Spot Welded Light Metal Alloys

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Abstract: The use of light metals today is of great importance, for example in the automotive, aviation and aerospace industries, where energy consumption is minimized and thus the economy is being attempted. By using light metals, weight is reduced so that energy is saved. Aluminum and magnesium alloys are particularly used thanks to their lightweight. Vehicles in the automotive, aerospace and space industries are expected not only to have lightweight but also high static and dynamic strengths since they are exposed to static and dynamic cyclic loads. However, the structural components can quickly become fatigued and fail under cyclic load due to the notch factor of the joining zones. Compared to the fusion welding method, joining of material is realized mechanically below the melting point of the material in the friction stir spot welding (FSSW) method. Thus, the fatigue strength of the assembly is much higher than that of the fusion welding. In this study, light metal alloy of magnesium AZ31B and aluminum EN AW 2024 were joined with FSSW method and mechanical properties of this joins were also carried out.

Key words: Friction stir spot welding, joining of magnesium, joining of aluminum, welding of light metals.

1. Introduction

In consequence of the limited energy resources in the world and the increasing awareness of energy saving in human beings, manufacturers in the automotive and aerospace industries are using lightweight metals to save fuel and thus saving energy in vehicles they produce [1-5].

There are various technical problems in the resistance spot welding, which is one of the joining methods in fusion welding of light metals. The most important of these is the realization of the joining above melting point, which burns and causes brittleness of the material, the joining defects and the notch factor; causing fatigue damage to vehicles or machines exposed to cyclical dynamic loads [6-11].

In this study, aluminum alloys (EN AW 2024) and magnesium alloy (AZ31B) sheets were lab-joined by using FSSW method, and mechanical tests results are given.

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2. Experimental

In order to verify the selected material, standard material tests were carried out. Tension-shear test and three points banding tests were also carried after joining the materials.

2.1 Base Material Tension Tests

Mechanical properties of base material were verified by using INSTRON 3369 tension test machine according to ISO 6892-1. The dimensions and picture of tension test samples are given in Figs. 1 and 2.

Tables 1 and 2 show the chemical composition and mechanical properties of magnesium alloy sheet AZ31B according to the standards [12].

Fig. 3 shows the tensile test sample of aluminum alloy EN AW 2024-T4 according to ISO 6892-1.

Tables 3 and 4 show the chemical composition and mechanical properties of aluminum alloy sheet EN AW 2024-T4 according to the standards [13].

Since the materials which are having *E* modulus lower than 150,000 MPa are investigated, tension test speeds were selected according to Table 3 in ISO 6892-1 which is 1 mm/min respectively 18 MPa/s.

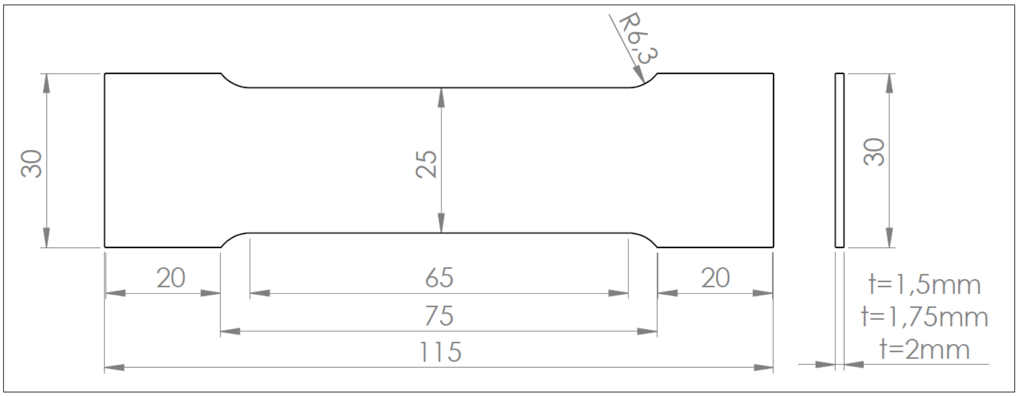

Fig. 1 Tension test sample dimension according to ISO 6892-1.

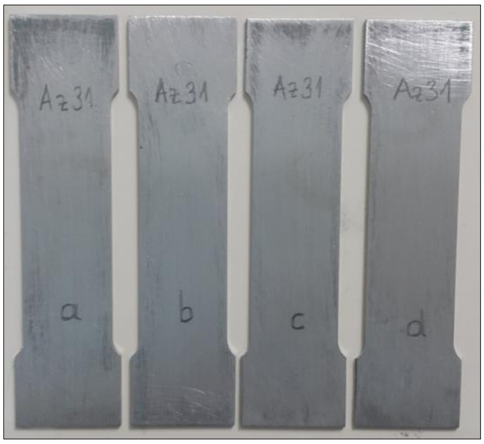

Fig. 2 Tensile test samples of magnesium alloy AZ31B-O according to ISO 6892-1.

Table 1 Chemical composition of magnesium alloy AZ31B [12].

Alloy	Al	Ca	Cu	Fe	Mn	Ni	Si	Zi	Mg
%	2.5-3.5	0.04	0.05	0.005	0.2-1.0	0.005	0.1	0.6-1.4	rest

Table 2 Mechanical properties of magnesium alloy AZ31B [12].

Temper.	Tensile strength (MPa)	Yield stress (MPa)	Elongation (%)
T4	240	145	≥ 7

Fig. 3 Tensile test samples of aluminum alloy EN AW 2024-T4 according to ISO 6892-1.

Table 3 Chemical composition of aluminum alloy EN AW 2024-T4 [13].

Element	Al	Cu	Mg	Mn	Fe	Cr	Zi+Ti	Zn	Si
%	90.7-94.7	3.8-4.9	1.2-1.8	0.3-0.9	0.5	0.1	0.15	0.25	0.5

Table 4 Mechanical properties of aluminum alloy EN AW 2024-T4 [13].

Temper.	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Hardness (HB)
T4	≥ 425	≥ 275	≥ 12	120

Fig. 4 shows the tension test results. Only two of the four prepared samples (a, b, c, d) gave a reliable results.

Table 5 shows the mechanical properties of 1.5 mm thick magnesium alloy AZ31B measured by the tension test with a tension speed of 1 mm/min.

Fig. 5 shows the tension test results for aluminum sheets. All four tests samples (1, 2, 3, 4) gave reliable test results.

Table 6 shows the mechanical properties of the aluminum alloy EN AW 2024-T4 material and the thickness of the 1.2 mm sheet measured by the tensile test at a speed of 1 mm/min.

Mechanical properties of magnesium alloy AZ31B and aluminum alloy EN AW 2024-T4 material were determined with the tensile tests. It was concluded that the provided values are in line with values in the standards, which corresponds to the criteria of the standards and therefore the tests are considered as reliable.

2.2 Tensile-Shear Test

Standard test samples (AZ31B) welded with shoulder profile type A were exposed to tensile-shear tests. The dimensions for friction stir spot welded samples are showed in Fig. 6. Fig. 7 shows the force-elongation test results for test speed of 10 mm/min. Average ultimate tensile strength of 4 EN AW 2024-T4 sample materials is 2,820 N given in Fig. 8.

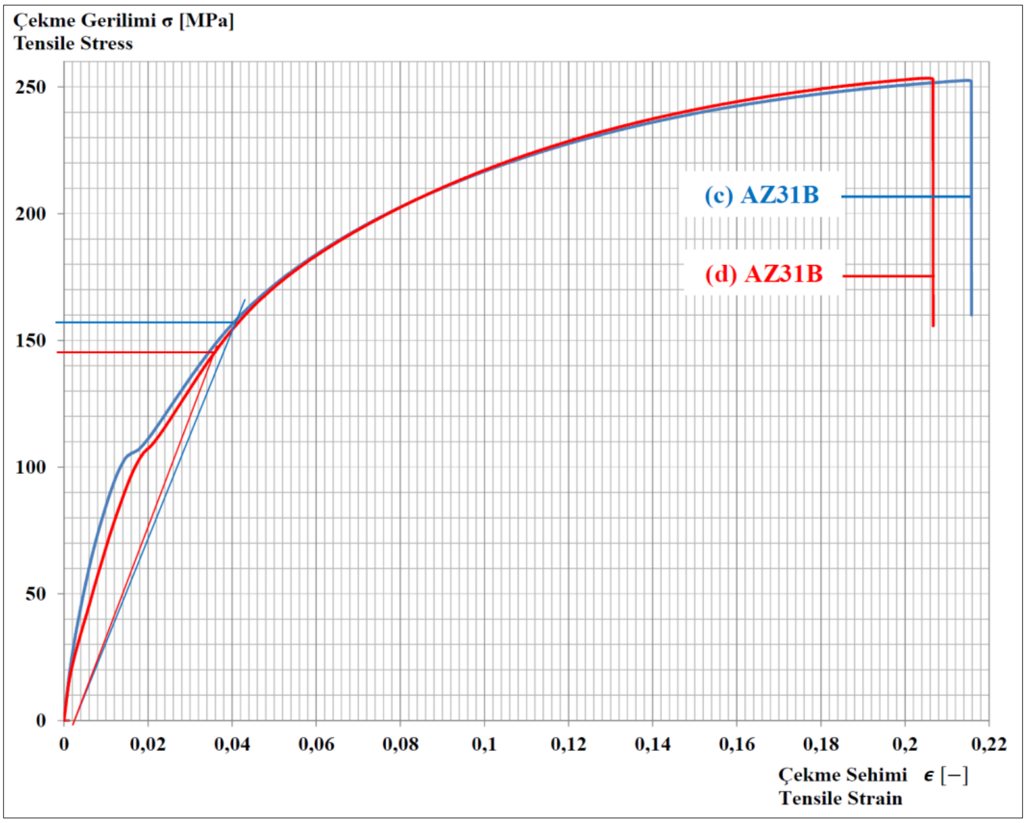

Fig. 4 Tension test results of 1.5 mm thick magnesium alloy AZ31B with a tension speed of 1 mm/min.

Table 5 Mechanical properties of 1.5 mm thick magnesium alloy AZ31B measured by the tension test with a tension speed of 1 mm/min.

Sample/material	Tensile strength σ_u [MPa]	Yield strength σ_y [MPa]	Yield rate A [%]
(c) AZ31B	252.6	156	21.8
(d) AZ31B	253.5	146	21.0
AZ31B (Avg.)	253	151	21.4

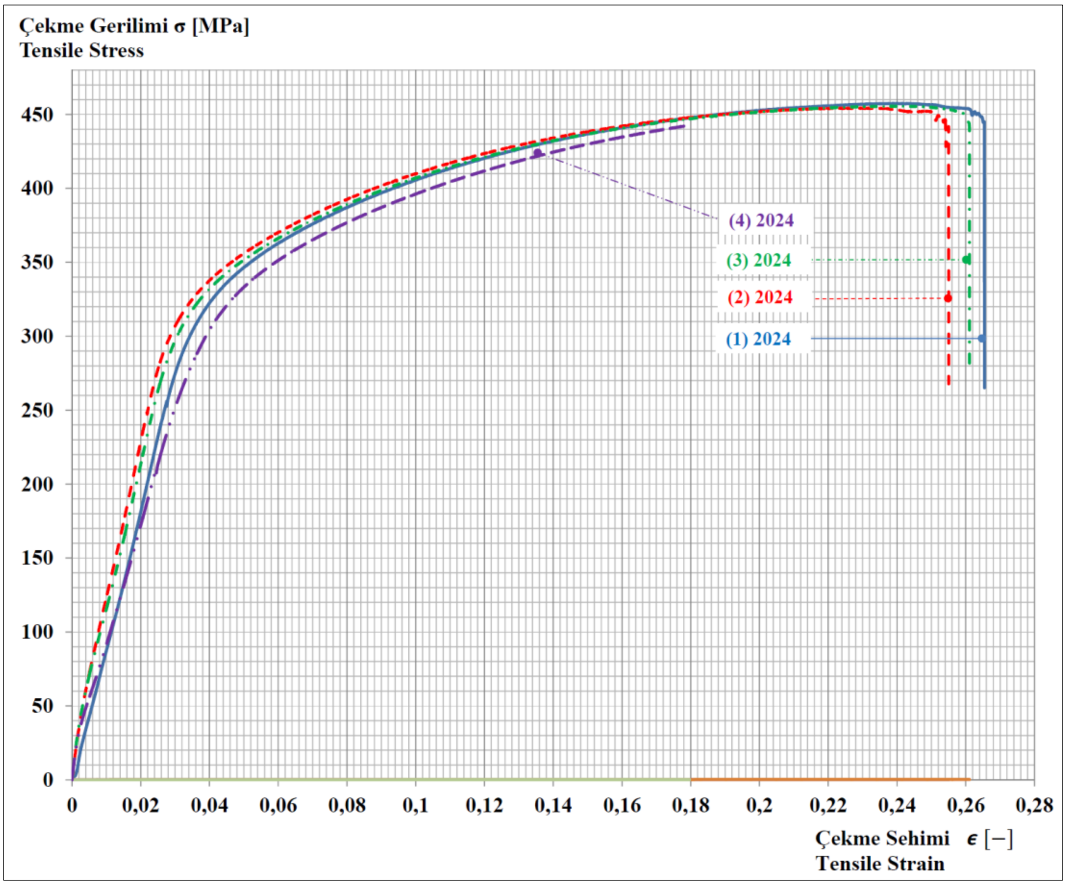

Fig. 5 Tension test results of 1.2 mm thick aluminum alloy EN AW 2024-T4 with a tension speed of 1 mm/min.

Table 6 Mechanical properties of 1.2 mm thick magnesium alloy EN AW 2024-T4 according to tension test with a tension speed of 1 mm/min.

Sample/material	Tensile strength σ_u [MPa]	Yield strength σ_y [MPa]	Yield rate A [%]
(1) EN-AW 2024	457.5	290	26.8
(2) EN-AW 2024	454.3	330	25.7
(3) EN-AW 2024	455.6	325	26.5
(4) EN-AW 2024	442.6	305	18.2
EN-AW 2024 (avg.)	452.5	312.5	24.3

Table 7 shows the tensile shear test results of different materials such as AZ31B and EN AW 2024-T4 with joining of same shoulder profile (A).

If we compare the average tensile forces obtained in tensile-shear tests to the tensile stress of the material, it can be said that this ratio of EN AW 2024-T4 material is bigger than that in AZ31B and therefore the joining of EN AW 2024-T4 is more robust.

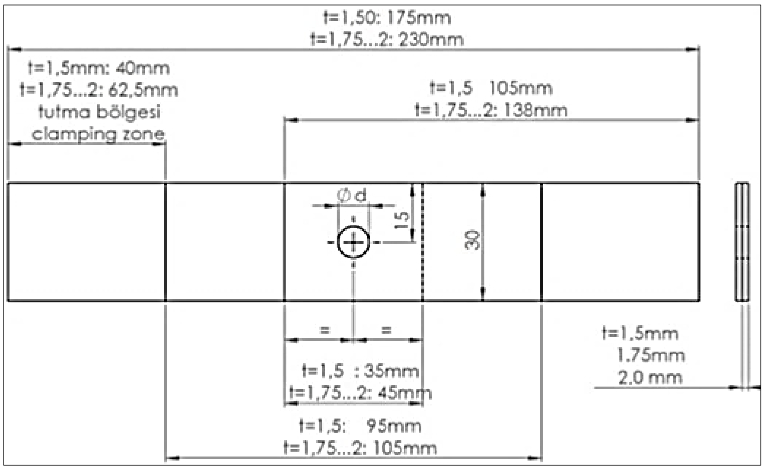

Fig. 6 Joining dimensions for the friction stir spot welding of the test samples.

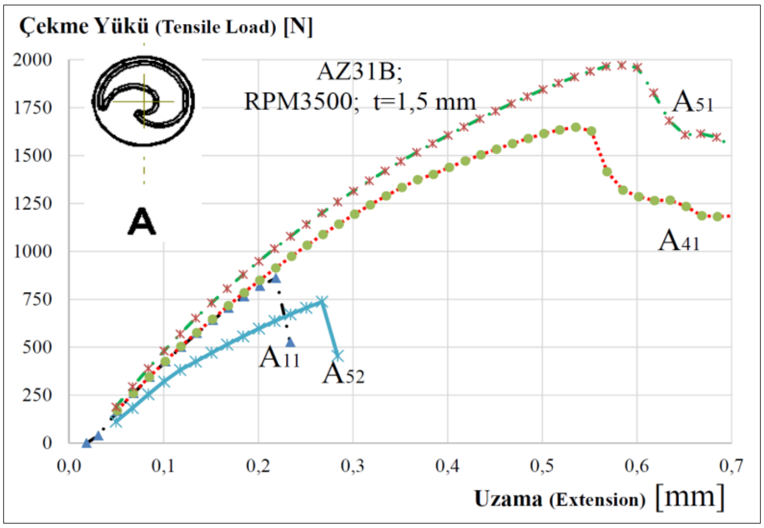

Fig. 7 Force elongation graphic of tensile, shear tests results of 1.5 mm magnesium alloy AZ31B samples, A11, A41, A51, and A52.

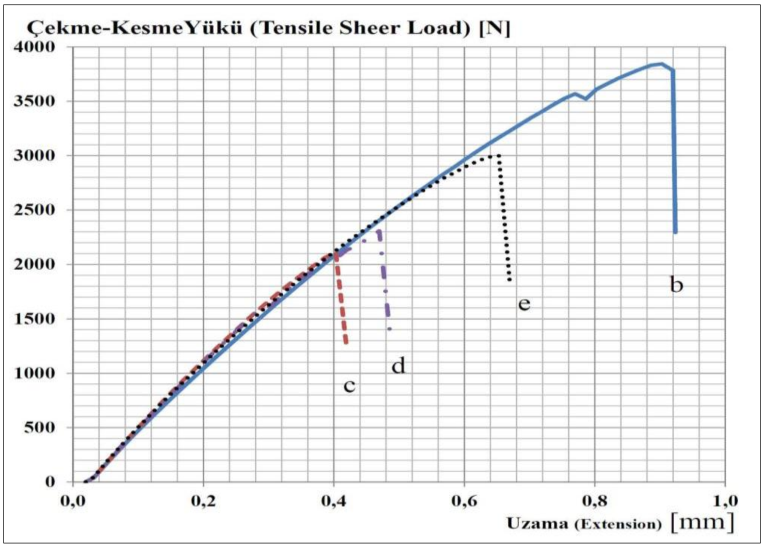

Fig. 8 Force elongation graphic of tensile, shear tests results of 1.2 mm aluminum alloy EN AW 2024-T4 samples, b, c, d and e.

Table 7 Comparison of tensile, shear test results of AZ31B and EN Aw 2024-T4 (Shoulder profile A).

Material	Ultimate shear force max. Fu [N]	Average shear force Fu [N]	Tensile strength fu [MPa]	Fu/fu [N/MPa]
AZ31B	1,500	1,290	240	5.4
EN AW 2024-T4	3,850	2,820	425	6.6

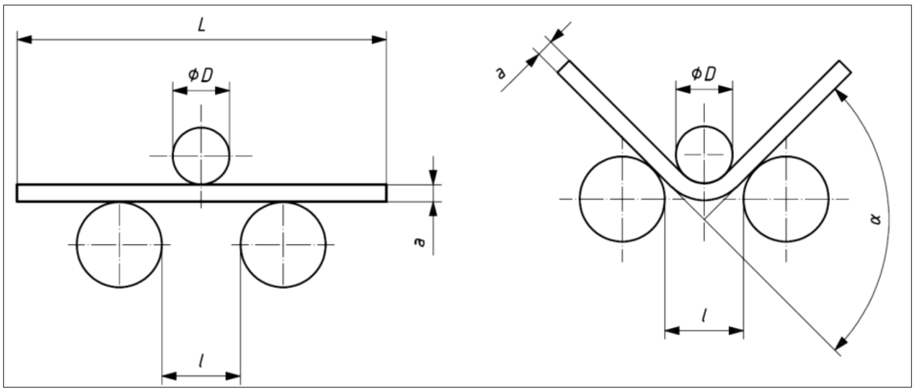

Fig. 9 Set up dimensions for three-point bending tests according to ISO 7038.

2.2 Three Points Bending Test

The set-up and its dimensions used for the three-point bending test according to ISO 7038 are shown in Fig. 9. According to this, a = 2 × 1.5 mm = 3 mm; D = 6 mm; l = 15.5 + D + 3a × a / 2 = 25 × 1.5 mm and the cylinder diameters of the supports were selected as d = 50 mm. An extra 15.5 mm has been added to the support pitch gauge 1 otherwise the lap area is touched by the support rollers during bending and thus causes incorrect measurement.

Figs. 9 and 10 graphically show the bending force vs. bending deflection values of the three-point bending test after joining of 1.7 mm and 2.0 mm magnesium alloy AZ31B sheets with FSW. Joining conditions a re 5-second plunge time and 15 seconds waiting.

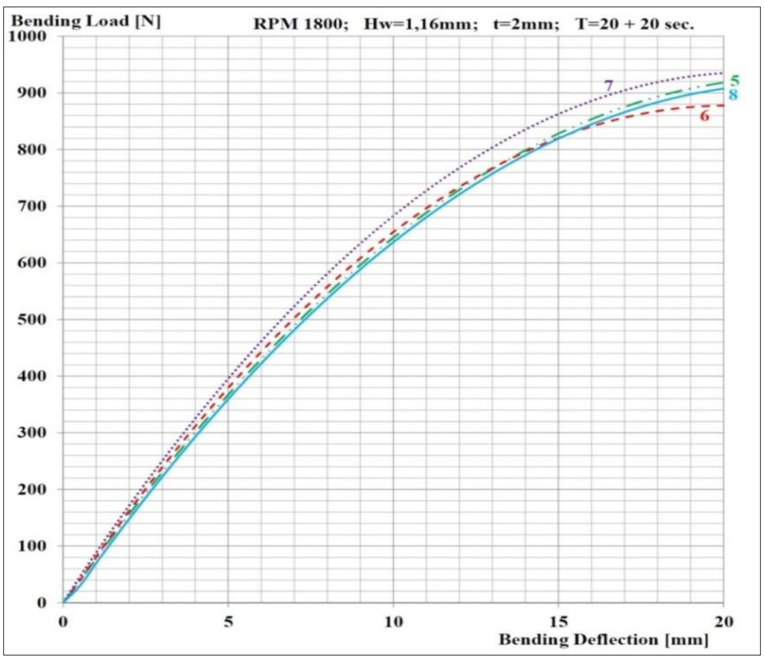

Fig. 10 Graphical representation of bending forces vs. bending deflection according to three-point bending test results of FSW welded 2.0 mm magnesium alloy AZ31B samples, 5, 6, 7, and 8.

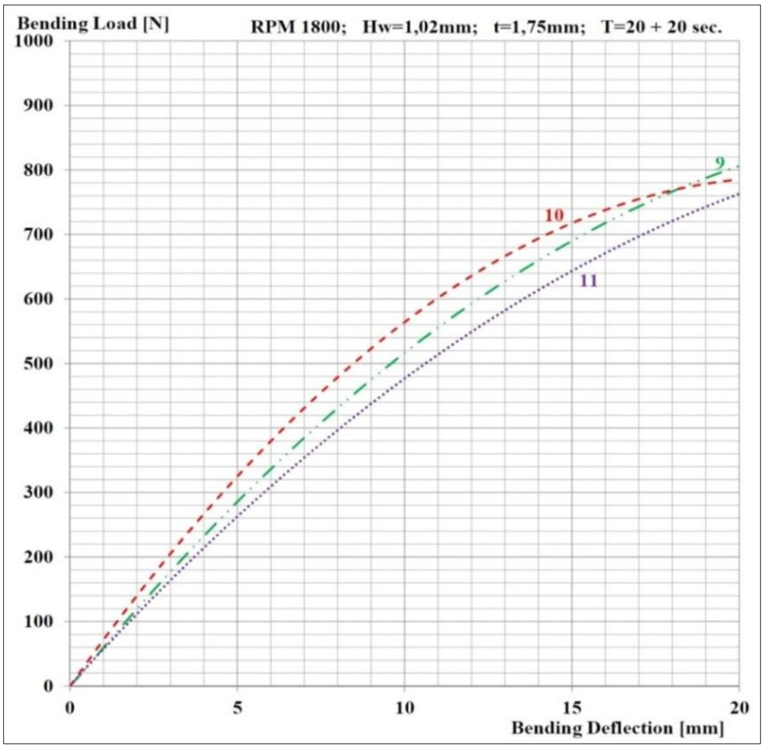

Fig. 11 Graphical representation of bending forces vs. bending deflection according to three-point bending test results of FSW welded 1.75 mm magnesium alloy AZ31B samples, 9, 10, and 11.

3. Results and Conclusion

- It was found that magnesium alloy and aluminum alloy thin plates can be joined together with a friction stir spot welding.
- Base materials used in this study: AZ31B and EN AW 2024, were tested and verified to be in accordance with the specifications given in the standard of mechanical properties.
- If the tensile forces of the base material are compared with the tensile force of the FSW materials, the tensile force in the joined material descends at least the half through the notch factor (about 2.5). This would not be the case if it were a continuous welding instead of a spot welding.
- Higher tensile-shear forces were obtained for aluminum alloy EN AW 2024 material joined with FSW compared to magnesium alloy AZ31B.
- If the three-point bending test results of different thicknesses (1.75 and 2.0 mm) of magnesium alloy AZ31B sheets compared, almost similar results were obtained.

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