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Araştırma Makalesi / Research Article

The Clinching Joints Strength Performance of EN 10346: 2015 DX52D + Z Sheets

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Keywords
Clinching; Joint strength; Metal forming; Joint quality; Joining test; Interlocking

Abstract

This study is based on the joint quality of zinc-coated EN 10346: 2015 DX52D + Z quality steel sheets with having different thicknesses, which are preferred in the automotive industry due to their formability. Joining problems in clinching applications with different positions and sheets of different thicknesses are discussed and experimental outcomes are discussed in terms of strength of joints. As a result of the tests carried out according to the standards, it has been found that the joining of the sheets with thickness close to each other is relatively good, as the thickness difference increases, the joint quality decreases and sometimes the joint does not form. It has been also found that if the thinner sheet is placed on the bottom die during clinching, a better joint strength is obtained.

EN 10346: 2015 DX52D+Z Plakaların Form-Punta Bağlantı Performansları

Anahtar kelimeler
Perçinleme; Bağlantı dayanımı; Metal şekillendirme; Bağlantı kalitesi; Bağlantı testi; Birbirine kilitlenme

Öz

Bu çalışma, şekillendirme kabiliyeti nedeniyle daha çok otomotiv endüstrisinde tercih edilen çinko kaplanmış farklı kalınlıktaki EN 10346:2015 DX52D+Z kalite çelik levhaların clinching teknolojisi ile yapılan bağlantılarının bağlantı kalitesi üzerine yapılmıştır. Özellikle clinching uygulamalarında karşımıza çıkan farklı pozisyon ve farklı kalınlıktaki levha birleştirmelerindeki bağlantı problemleri ele alınmış ve bağlantı kalitesi için genel bir değerlendirme yapılmıştır. Standartlara uygun olarak gerçekleştirilen testler sonucunda birbirlerine yakın kalınlıktaki levhaların bağlantılarının nispeten iyi olduğu, kalınlık farkının arttığında, bağlantı kalitesinin azaldığı ve bazen bağlantıların gerçekleşmediği görülmüştür. Bağlantı sırasında daha ince olan plakanın alt matris tarafında olması, çok daha iyi bir bağlantı dayanımının sağlanabilmesinin bir gereği olduğu belirlenmiştir.

1. Introduction

Although the clinching is an old technique, it is considered as an alternative solution due to the increasing need for lightweight construction and various applications that have been developed on it. Clinching technique has become a necessity especially in automotive and aircraft industries where materials with different properties such as, aluminum and magnesium alloys, carbon fiber reinforced plastic and high strength steel are used in hybrid structures. When this technique is applied, it is possible to eliminate problems such as property degradation, stress concentration, intermetallic compounds, etc. on the construction of hybrid structures. Increasing interest in the joining of lightweight materials in parallel with the development of new technologies has led to the emergence of different variants of the clinching technique. The first examples of these new forming technologies are; self-piercing riveting (He *et al*. 2013), Clinch-bonded hybrid joining (Lei *et al*. 2018) and a single-lap joint (He *et al*. 2012). Even in recent years, hybrid techniques such as heating and cooling processes (Chen *et al*. 2018), resistance spot welding and Electro-Hydraulic (Zhang *et al*. 2017, Salamati *et al*. 2019) have been used together in addition to applications using electromagnetic effect (Babalo *et al*. 2018) to increase the punch to high speeds. Studies on the traditional clinching technique have improved this technique to eliminate the problems that arise in the applications of the clinching technique and to accelerate the application of some plastically forming resistant materials such as high strength steel sheets. Initial studies were on the punch and die structure such as roller clinching, rectangular forming and expandable die, laser shock clinching, welded-clinched, electro-hydraulic and so on. It continues with hybrid applications that are quite different from the structures of the traditional technique. Clinching technique has some advantages over other alternative techniques. The ability to apply to a wide variety of materials means less damage to the sheet used, lower cost, less surface preparation, less-skilled labor demand, environmentally friendly applications, and better mechanical properties.

The clinching technique, which is a mechanical clamping process, is the technique of non-removable joints of the sheets to be joined with a local plastic deformation at the application area without any additional elements (in some applications using an additional element). Using a die and a punch, the operation of clamping carried out due to the material flow, in which the sheets to be joined are pushed into the die cavity. Thus, the materials that are ductile form an interlock in the die cavity.

In the clinching technique, the structure of the interlocking form of the sheets to be joined is the most important element determining the strength of the joining. For an understanding of the parameters that provide this form, Lee at al. (2017) studied the joining of DP780 and Al5052 sheets. Due to the different ductility values between the materials, such as necking in the upper sheet and cracks in the lower sheet, do not allow the locking in the joining area. The effect of many parameters on the ability to form a joint between used material was investigated using finite element analysis and it has been understood that the die radius, die depth and die groove shape greatly affect the quality of the joints. They stated that the die radius is the most important process parameter and should be determined by considering the forming volume. They observed that the internal locking was a problem in the large die radius values, that the length of the locking was prolonged by the increase in the die depth, but in the lower sheet, that the large die radius values caused cracks.

Using advanced high strength steel sheets, Mucha (2017) studied the effect of die geometry parameters such as die radius, die depth and die groove on the final locking size and maximum forming force, process parameter effects on the joinability. Die groove width was determined to be the most important parameter and this parameter affecting the energy consumption and material flow effect of the process. Mucha (2017) showed in his studies that the increase in compressive force does not make many changes in the neck thickness but it causes a decrease in the excess bottom thickness. The study also found that the reduction of the gap between the punch and the die surfaces caused the pressure towards the lower sheet in the groove region of the flowing material of the upper sheet.

Various punch and die geometries have been simulated using a finite element analysis (FEA) by Paula *et al.* (2007) who tried to determine the effect of changes in joint undercut and neck thickness and also confirmed the importance of a sufficient undercut size on the joint force. Changes in punch taper and tip diameter, die diameter and groove thickness, groove shape and depth showed that it did not make beneficial changes to the lower cut size, but may cause neck thickness problems. Concerning a slightly tapered die and reduced depth of recess, the protrusions in the punch corners and the constraints in the upward movement of the sheet resulted in that the lower cuts of the better form are associated with high release forces.

Mucha and Witkowski (2014) working on the effects of variation of the joint embossment thickness on joint strength, showed that maximum joint strengths were obtained in H and T-type tests. By applying complex loads with this type of test, both the changes in loading direction on maximum loading and the shear tear effect of the gap left between the punch and die were obtained. Mucha and Witkowski (2014) also studied clinch-rivet type joining and showed that higher strengths can be obtained compared to traditional clinch technology. It was also found that a reduction in the embossment thickness makes the flow of material in the die cavity difficult and may result in rapid corrosion and porosity in zinc-coated sheets.

Lee *et al.* (2010) defined an analytical model which is a function of undercut and neck thickness and obtained the tool geometry used in reverse order using the shape parameters for the required joint strength. Mechanical clinching tools joining Al6063 alloy sheets are designed by the recommended method. FE-analysis and mechanical clinch tests were performed for optimum conditions obtained from the proposed design method and showed that the model was compatible. As a result of the impact test, it has shown that the clinch technique can produce similar impact resistance with self-piercing riveting and is thus suitable for use in the automotive industry.

In the riveted two-step clinching technique, the riveting procedure is applied in the first step. Then, in the next step, the mechanical clinching and upsetting with a clinch-rivet process is continued. Chao *et al*. (2016) applied different riveting force to the joints made by using Al6061 alloy sheets, geometric parameters, material flow and mechanical properties of the joints were investigated with an experimental method. According to the results, the cross-tension and tension-shearing strengths were higher than the traditional clinch method. It has also shown that this application is also better in damage processes. Chao *et al*. (2019) studied three different reshaping processes after the traditional clinching process and showed that riveting reshaping on the Al6061-T4 sheets gave better mechanical properties than the others.

The types of damage seen in clinching joints are divided into four types(neck-hybrid neck fracture, button-hybrid button separation. Lei *et al*. (2019) studied these types of damage occurring in clinching joints, using a factor calculated from the cross-sectional parameters of a joint, evaluating a coefficient of damage modes. The mechanical properties of the obtained joint and the different damage modes with this varying coefficient were investigated. The results showed that the coefficient in experiments using different materials can be used as a reference to control the mechanical properties of clinching joints.

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In the study of Varis (2004), the applications that began with the clinching technique of steel sheets with different strength values, which are still widely used in the automotive industry, were later applied by Lambiase *et al*. (2015) as with the studies continued with the joining of aluminum alloys to each other. Titanium, an indispensable material in the automotive industry as well as in the aircraft and space industries, was studied for clinching experiment by Zhang *et al*. (2017), He *et al*. (2015), apart from He *et al*. (2017), Neugebauer *et al*. (2008) carried out studies on magnesium, and finally Baoying *et al*. (2015) measured clinching performances of copper sheets. In some studies on the performance of these types of joints, the joining performances of two different metals were examined such as Abe *et al*. (2012), Jiang *et al*. (2015) and Mucha et al. (2013) on steel and aluminium joints, Lambiase *et al*. (2018) on titanium and aluminium joints, Li *et al*. (2013) on magnesium and aluminum joints, Wang *et al*. (2018) studied the clinching performance of different materials such as copper foil and perforated steel sheet. Unlike metal joints, Lee *et al*. (2014) studied the clinching steel/aluminum and carbon fiber reinforced plastic combinations, Lambiase *et al*. (2017) steel and polycarbonate sheets and Lambiase *et al*. (2015) studied the joints of aluminum and polystyrene.

In the study, using EN 10346: 2015 DX52D + Z, one of the sheet materials used in the automotive industry, different thicknesses and different joint positions affecting the joint strength quality were evaluated according to their conditions. It is understood that in order to increase the strength values of the joints, the thickness of the sheet, the ratio of the thicknesses used and the placement position of the sheet or the die-punch should be selected very carefully.

2. Materials and methods

2. 1. Clinching mechanism

Conventional clinching is a clamping process using a simple set of tools including dies and punches, forcing the sheets to be joined in a local area without using any additional material. The magnitude of this force varies depending on the geometry of the tool and the properties of the sheets to be joined. It is an economical method because it does not require any additional material and the toolsets are long-lasting. The technique does not require both a preparation and skilled workmanship for the machines used. Fig. 1 shows the elements of a conventional clinching toolset. Die and punch in different geometric forms such as circular, rectangular, coaxially were designed according to the thickness of the sheets to be clinched and these are the two basic elements of the clinching technique. The rubber part attached to the blank holder, because of its properties, presses the sheets into the die and both restricts the movement of the form remaining during joining and helps to remove the stuck sheet from the punch due to friction during separation.

The steps of a simple clamping process are shown in Fig. 2. The punch pushes the sheets to be clinched into the die, while the blank holder prevents movement of the sheets. As the punch moves upwards, it helps to release the clinched sheets from the punch. The basic geometric form is punched and the external geometric form is determined by the die in obtaining the clinching form. However, it has been the subject of many studies that many parameters play an important role in the formation of this form and to determine which one of these parameters is effective on the geometry of the clinching form. Fig. 3 is a cross-sectional view of a joint form and names given to the resulting geometries.

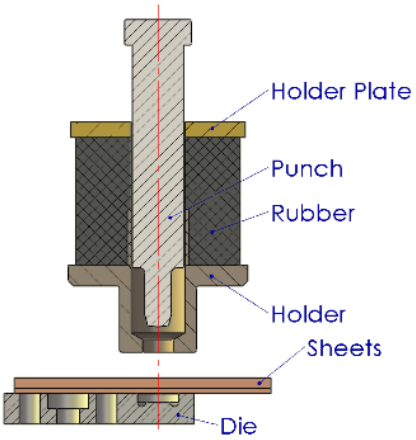

Figure 1. Elements of a conventional clinching tool

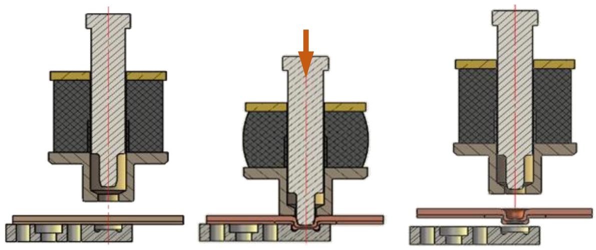

Figure 2. The basic principle of the clinching process

The magnitude of the tensile and shear stresses on the joint is related to the value of bottom protrusion (a), final bottom thickness (b), undercut (c) and neck thickness (d). The punch radius (Ra), die radius (Rb) and die depth/protrusion (e), which are the three basic geometries of the tool used, are the most basic parameters that determine the undercut and neck thickness. In general, if the punch radius increases, the value of the undercut thickness increases accordingly when other geometries remain unchanged; Similarly, when the radius of the die increases, the neck thickness increases, but the

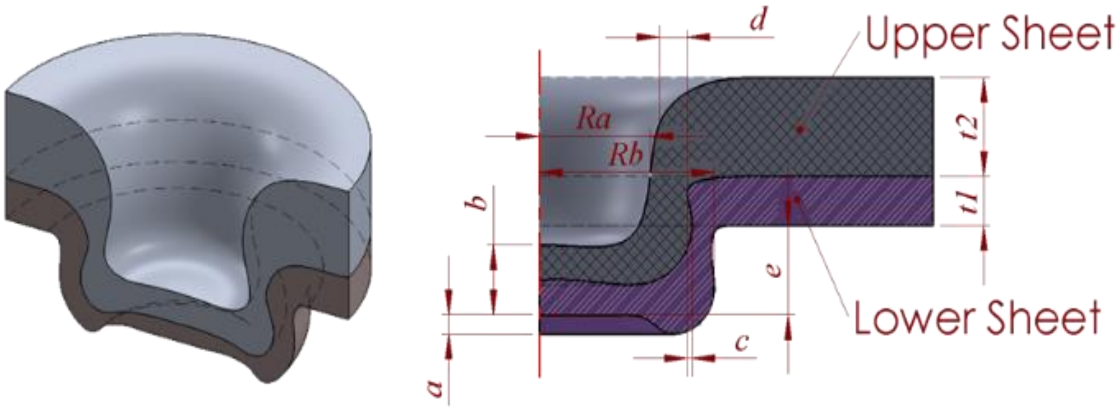

Figure 3. Cross-sectional view of the clinched joint form and nomenclature of its geometries

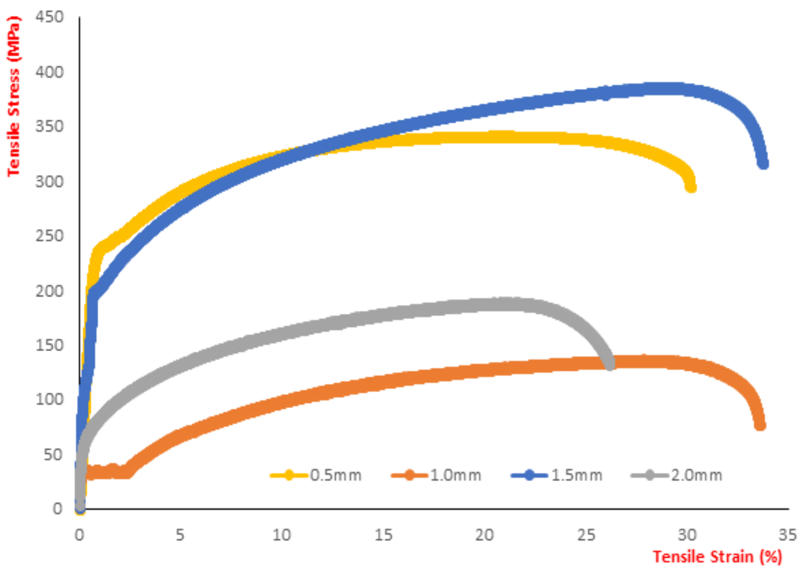

Figure 4. Mean tensile test curves of different thickness sheets (TS EN ISO 8692-1)

value of the undercut decreases, and when the depth of the die increases, the value of the undercut increases, but the neck thickness decreases(Mucha 2011, de Paula *et al*. 2011, Mucha 2014, Lee *et al*. 2010, Baijun *et al*. 2012, Oudjene *et al.* 2008, Oudjene *et al.* 2018, Lambiase *et al*. 2018)

2. 2. Materials

The joining test was performed on steel sheet produced by Eregli Demir Çelik Factory with a code number of 1312-DX52D + Z (acc.to EN 10346) of thickness 0.5-2 mm and galvanized with coating. Basic mechanical properties and the chemical composition are presented in Table 1. However, tensile tests performed under TS EN ISO 8692-1 standard showed that sheet properties with different thicknesses vary as shown in Fig. 4. When the tests were examined, it was understood that although the same factory products were used, the mechanical properties differ significantly not only for different thicknesses, but also for different plates of the same thickness. This revealed the need to calibrate when evaluating test results.

Table 1. Chemical composition and mechanical properties, Erdemir 1312 (EN 10346: 2015 (DX52D + Z))

C	Si	Mn	P	S (max.)	Ti
0.12	0.50	0.60	0.10	0.045	0.30

$R_{p0.2}$ (N/mm²)	R_m	A_{80}
140-300	270-420	26

3. Experimental procedure

3.1. Specimens preparation

TS EN ISO 14273 and TS EN ISO 14270 standards are related to specimen dimensions and procedure for shear and mechanized peel testing resistance spot, seam and embossed projection welds. However, similarities show that this standard can also be used in clinch tests. Specimens are cut from the steel sheet for each thickness by CNC NUKON laser cutting machine by taking into consideration of the appropriate states and directions, deburred and cleaned of dust and oil, then grouped for joining. Similarly, TS EN ISO 6892-1 has been applied for tensile testing of metallic materials at room temperature. The bending procedure for mechanized peel testing was applied very carefully. Fig. 5 shows samples prepared for testing.

Figure 5. Test device & samples prepared and grouped for tests

3.2. Tests

Samples prepared and grouped according to the standards for shear and mechanized peel tests were assembled with the assembly machine shown in Fig. 6. This machine is specially designed for clinch tests.

Figure 6. Clinch sample mounting machine and apparatus

The machine includes a TOX electro-pneumatic hand unit and a specially designed apparatus for joining under the standard. The apparatus is used for easy adjustment to the dimensions and positions specified in the standards for testing and for fixing samples during clinching. Additional support sheets are provided at the ends, as shown in Fig. 7, to regulate the size difference that occurs during both joining and testing and thus positioning them parallel to the jaws.

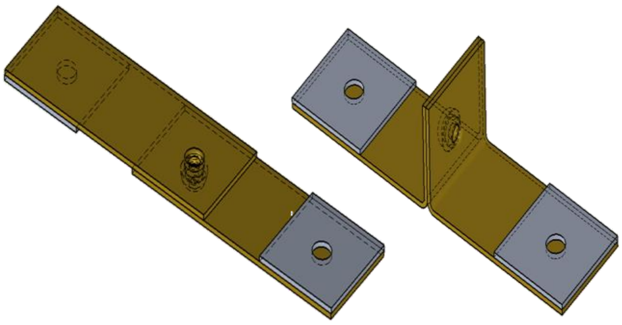

Figure 7. Positioned samples for shear and mechanized peel test

The tests were performed on the INSTRON 8801 test machine in the AKU Mechanical Test Laboratory. This class-A calibrated test machine is a device with a hydraulic pump and video-extensometer that can be used for all kinds of tests, including fatigue. The joined samples were tested on the test device with almost twice the minimum number of tests specified in the standard, carried out at a rate of 2 mm/min and continued until the samples were completely separated from each other. The separation load values given in the tables are taken as the maximum load values obtained in the tests.

4. Results and Discussion

The tests were repeated for the different combinations of sheets of four different thicknesses. Sheets with different thicknesses were placed interchangeably to be on top or bottom, For the 16 groups formed, the test results are given according to the upper sheet thickness in Table 2 and the lower sheet thickness in Table 3. In all tables, the average maximum separation load for the tests performed using standard test procedures and the standard deviation values of the test results are presented. Not only working with different plates (for the same thickness), also the regionally

Table 2. Shear and mechanized peel test results according to upper sheet thickness

Group Number	Position / Sheet Thickness (mm)		Separation Load (N)			
	Upper	Lower	TS EN ISO 14273	Standard Deviation	TS EN ISO 14270	Standard Deviation
I	0.5	0.5	317.95	24.2%	29.50	7.3%
II	0.5	1	631.10	6.8%	184.33	4.9%
III	0.5	1.5	595.91	7.4%	253.62	7.5%
IV	0.5	2	x	x	x	x
V	1	0.5	2522.75	1.8%	37.04	23.4%
VI	1	1	2297.17	2.2%	353.80	3.1%
VII	1	1.5	2397.88	1.5%	576.81	3.5%
VIII	1	2	1736.25	3.3%	444.71	4.0%
IX	1.5	0.5	2929.63	1.2%	80.57	13.3%
X	1.5	1	4073.25	0.6%	323.66	5.8%
XI	1.5	1.5	3721.33	0.6%	435.43	5.3%
XII	1.5	2	2736.13	2.2%	394.22	21.5%
XIII	2	0.5	2844.25	1.4%	76.54	24.2%
XIV	2	1	4207.99	2.9%	160.21	36.1%
XV	2	1.5	x	x	x	x
XVI	2	2	x	x	x	x

Table 3. Shear and mechanized peel test results according to lower sheet thickness

Group Number	Position / Sheet Thickness (mm)		Separation Load (N)			
	Lower	Upper	TS EN ISO 14273	Standard Deviation	TS EN ISO 14270	Standard Deviation
I	0.5	0.5	317.95	24.2%	29.50	7.3%
V	0.5	1	2522.75	1.8%	37.04	23.4%
IX	0.5	1.5	2929.63	1.2%	80.57	13.3%
XIII	0.5	2	2844.25	1.4%	76.54	24.2%
II	1	0.5	631.15	6.9%	184.33	4.9%
VI	1	1	2297.17	2.2%	353.80	3.1%
X	1	1.5	4073.25	0.6%	323.66	5.8%
XIV	1	2	4207.99	2.9%	160.21	36.1%
III	1.5	0.5	595.91	7.4%	253.62	7.5%
VII	1.5	1	2397.88	1.5%	576.81	3.5%
XI	1.5	1.5	3721.33	0.6%	435.43	5.3%
XV	1.5	2	x	x	x	x
IV	2	0.5	x	x	x	x
VIII	2	1	1736.25	3.3%	444.71	4.0%
XII	2	1.5	2736.13	2.2%	394.22	21.5%
XVI	2	2	x	x	x	x

changing mechanical properties of the plates but also effects such as instantaneous pneumatic changes, temperature, surface quality, dust, oil, surface linearity cause deviation. It is observed that the deviation value increases especially in the joints where very thin sheets are with each other and the thickness ratio is high. In some examples of these joints, the strength value is too low or no joint has been observed due to insufficient locking. In Figure 8, joint separation load values are given according to the thickness of the upper sheet, which varies according to the thickness of the sheet in the lower position of 0.5, 1, 1.5, 2 mm, respectively. Thus, the change can be observed better than a fixed lower and a fixed upper sheet thickness value. In Table 2, group XIV for shear test, group VII for peel test gives the largest separation load values.

Although generally mandatory during applications, it becomes important to select which sheet to be selected at the bottom if the option to be clinched at the top or bottom. The results show that good strength values of up to five times can be achieved if the sheets in groups III and V in Table 2 are at the top or bottom, as shown in the example.

To generalize, the thinner selection of the lower sheet guarantees a high clinching strength. The most important data obtained from the tests is the necessity of choosing an appropriate die according to the thickness of the sheet to be used in the application. The die set used is a maximum of 4 mm.

Although it can be used according to the thickness, some thickness combinations could not be established. In Table 2, IV., XV. and XVI. interlocking cannot be achieved in groups. The joining problem is seen in the form of fracture in the joints where the thickness ratio is very high, and in others the geometric insufficiency of the S form occurs. It may be wrong to evaluate the values given in Table 2 and Table 3 according to their thickness because a sample with a total thickness of 2 mm is expected to have twice as much strength as a sample with a total thickness of 1 mm. Since the strength characteristics of the sheets used were also different, the test results were calibrated to the smallest thickness as given in Eq. 1. to evaluate them all together. Thus, it will be easier to understand how many times the strength values are actually smaller than those measured for the smallest sample thickness. Fig. 9 shows the calibrated separation load ratios of joint.

$$\gamma_{t_{min},t_{min}}^{t_1,t_2} = \frac{\left(t_1 * \sigma_{max}^{t_1} + t_2 * \sigma_{max}^{t_2}\right) * F_r^{t_1,t_2}}{\left(t_{min} * \sigma_{max}^{t_{min}} + t_{min} * \sigma_{max}^{t_{min}}\right) * F_r^{t_{min},t_{min}}} \quad (1)$$

In the equation, $\gamma_{t_{min},t_{min}}^{t_1,t_2}$, t_n, F_s, $\sigma_{max}^{t_n}$represent the separation load ratio according to the weakest thickness, sheet thickness, separation load and maximum tensile stress of the sheet, respectively. The calibrated values show us that when the thicknesses change, the values are much larger than expected regarding the minimum joint thickness. In other words, the test values for the minimum thickness appear to be much smaller than expected. As in Table 2 VII, although the thickness ratio is only 1.67 (2.5 mm / 1.5 mm), the strength ratio can be 25 times higher, that is, if we use 0.5 mm thick sheet instead of a 1.5 mm sheet, the joint strength decreases 1/25 times although the thickness ratio is about 1.5 / 2.5. It is more accurate to explain the difference here with the structure of the joint form. It is seen that the structure of the lock/clinch form changes according to different strengths and different thicknesses. Studies have shown that the most important parameter on the flow effect in the die is the geometry of the die.(Lee *et al*. 2010, Mucha 2011, Lee *et al*. 2010). However, it should be remembered that sheet thickness, thickness ratios and material properties should also be taken into account.

The most basic indicator that determines the strength of the joint is the structure of the interlocking form. The geometries and material properties of the die set and the sheets used affect the structure of this form. Fig. 10 also shows XIV. The sectional view of the group sheets shows that there is an interlock in the joints. The properties and thickness of the sheet materials used here indicate that the greatest strength can be expected when evaluated together with other groups.

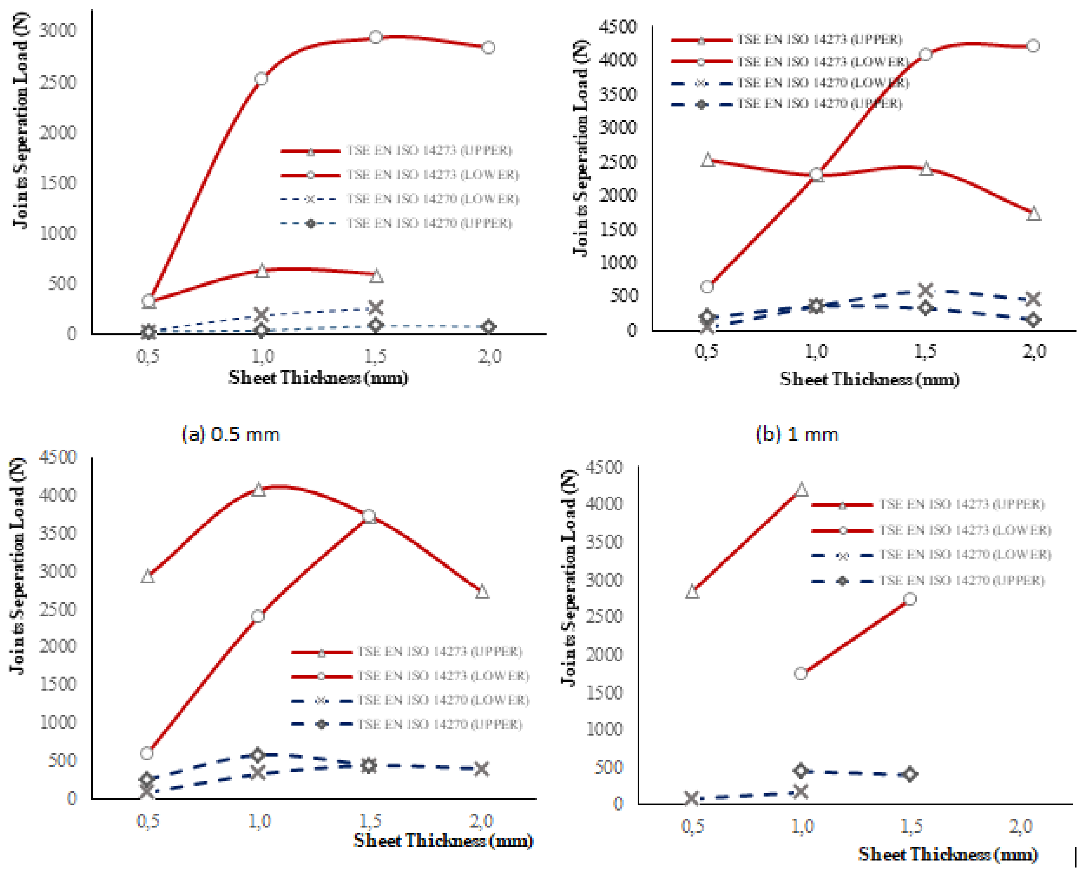

Figure 8. Joints seperation load according to bottom sheet thickness (a-0.5mm, b-1mm, c-1.5mm, d-2mm)

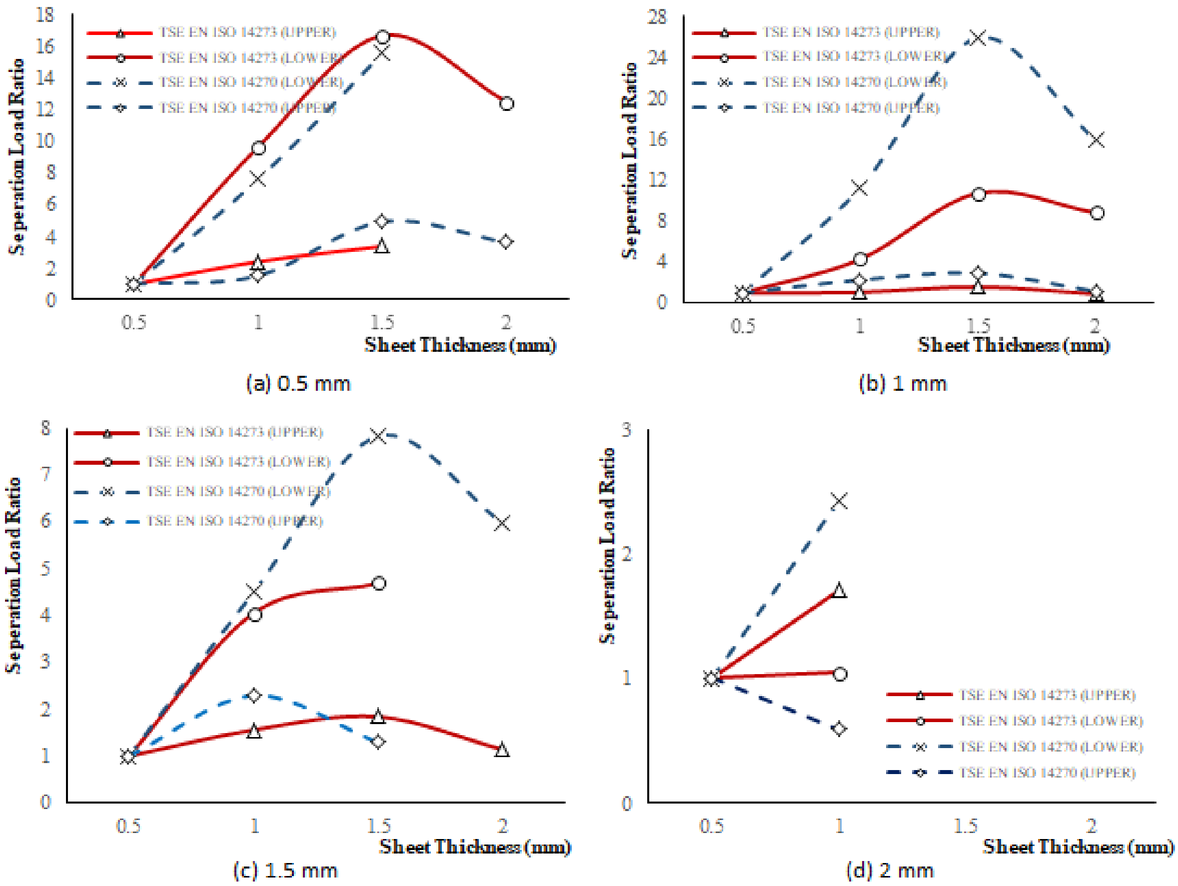

Figure 9. Ratios of calibrated joint seperation load (a-0.5mm, b-1mm, c-1.5mm, d-2mm)

The reason for having the largest value in the shear test is that both the undercut and neck thickness values reach a sufficient value. In Fig. 10b, VII. the cross-sectional view of the group sheets reveals the reason for obtaining the largest value in the peel test. Due to the movement of the material during forming, the lower sheet fills the die groove and forms a wider S-form. An adequate interlocking as well as a large undercut size provide a greater resistance to peeling during the test. In Fig. 10c, d, two examples of joints are not provided. IV., XV. and XVI. No joining could be made for the groups. As L. Lei emphasized in his studies, the thickness ratio of sheet metal is the most important parameter in the occurrence of damage(Lei *et al*. 2019). The reduced neck thickness causes rupture at the top of the joint, as shown in Fig. 10d, the insufficient die width cannot provide the form S required for clinching, making the material difficult to flow.

5. Conclusions

The sheets of different thicknesses and placed at positions in the die are joined with clinching technique and standard shear and peel tests are applied to the prepared samples and the following conclusions can be drawn:

(1) The peaks shown in the graphs indicate that thickness ratios will provide the best joint strength when remaining within certain limits. This is the only way to determine the geometry of the die set in the case of predetermined sheet thicknesses.

(2) Where the choice of sheets to be used for the joining is unclear, a large thickness ratio reduces the clinch strength or no joining is achieved.

(3) When the die set sheet thickness usage limit is approached, a high resistance to forming sheets possess problems in joining applications.

(4) If there is no requirement in the selection of the positions of the lower and upper sheets, it is determined that the thinner sheet should be placed on the die side, so that a better joining can be provided.

(5) Although the maximum load for Clinch technology is very low for industrial application, suitability for a wide variety of material combinations according to the spot welding, cleaning, robotic application tendency and aesthetic properties can be offered. In addition, one of the most important gains of the technique is its long fatigue life.

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The author declare no conflict of interest

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