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Influence of Cut Out Way on the Elastic-Plastic Behavior of AL-Cu Alloy

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Abstract

The influence of cut out way on the elastic-plastic behavior of AL-Cu alloy was studied in the present work experimentally and numerically using finite element method with aid of ANSYS-11 software. Central circular hole were introduced in (ASTM B 557-02a) tension specimens of alloy using drill and punch at cold and warm working conditions with (3.5, 4.25 and 6) mm diameters. Based on the results from experimental tension tests, as the hole diameter increases the mechanical properties of the alloy decreases. Tensile strength and yield stress with using bunch are less than that of using drill by 4% and 6% at cold condition, while at warm working condition by 34% and 42% respectively. But the elongation at maximum tensile strength of using punch is greater than that of using drill at cold working condition and vice versa at warm working condition. The fractures with using punch happen faster than that of using drill at lower strain rate. The apparent stress concentration factor ranged from 1.19 to 2.9 with using drill, and from 1.25 to 3.39 with using punch. The numerical results present the von Mises Stress distribution to identify the location that possibly initializes the fracture, and to estimate the stress concentration factor in which ranged from 2.13 to 2.39 and have reasonable agreement results with literatures.

Keywords: cut out way, stress concentration, mechanical properties.

تأثير طريقة القطع على التصرف المرن - اللدن لسبيكة الالمنيوم-نحاس

الخلاصة

في هذا البحث تمت دراسة تأثير طريقة القطع على التصرف المرن-اللدن لسبيكة الالمنيوم-نحاس عمليا وعدديا باستخدام طريقة العناصر المحددة بمساعدة برنامج (ANSYS-11) على الحاسبة. تم عمل ثقب دائري مركزي في عينات اختبار الشد (ASTM B 557-02a) باستخدام المثقاب والسلبك وعند ظروف تشغيل على البارد و على الساخن وعند أقطار (3.5, 4.25, 6) ملم. حيث بينت نتائج الاختبار العملي ان الخواص الميكانيكية تقل كلما ازداد قطر الثقب وان مقاومة الشد واجهاد الخضوع باستخدام السلبك تقل عن مثيلاتها باستخدام المثقاب بنسبة 4% و 6% عند التشغيل على البارد و بنسبة 34% و 42% عند التشغيل على الساخن على التوالي. ان الاستطالة عند مقاومة الشد الأعظم باستخدام السلبك تكون اكبر منها باستخدام المثقاب للتشغيل على البارد والعكس بالعكس للتشغيل على الساخن. الكسر يحدث عند استخدام السلبك اسرع منه عند استخدام المثقاب. ان معامل تركيز الاجهاد الظاهري يتراوح من 1.19 الى 2.9 باستخدام المثقاب

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ومن 1.25 الى 3.39 باستخدام السلبك. نتائج التحليل العددي تظهر توزيـــع اجهـــاد (von Mises) والذي يساعد على استدلال موقع بداية حدوث الكسر وكذلك حساب معامل تركيز الاجهاد والذي وجد بين 2.13 و2.39 وهذا يعطي توافقا مقبولا مع النتائج الموجودة في الدراسات السابقة.

الكلمات المرشدة: طريقة القطع، تركيز الاجهاد، الخواص الميكانيكية.

Symbols

E	Modulus of Elasticity (N/mm^2).
K	Stress concentration factor.
P	Load (N).
TS	Tensile strength (N/mm^2).
d	Diameter (mm)
e (%)	Elongation at maximum tensile strength.
σ_y	Yield stress (N/mm^2).

Subscript

a	apparent.
H	With hole
max	maximum.
nom	average.
O	without hole.

Introduction

The metal cut out play an important role in the performance of machined components design. The behavior of machined components can be enhanced or impaired by cut out metal. The cut out used for reduction the weight of the components, improve the component balance, fastener (bolt, nut and rivet), and passing pipe, wiring, etc [1]. as shown in figure (1). But the cut out became as a stress raisers (stress concentration region) [2]. So the cut out way play an important role in the surface texture and surface integrity of holes and must be considered in a thorough design evaluation.

The primary objectives of this study were to quantify the influence of cut out way on the elastic plastic behavior of AL-Cu alloy in (ASTM B 557-02a) tensile test. The cut out way used to introduce central circular hole. The cut out way include machining type and machining working conditions. The machining done by using drill and punch, while the machining working conditions done at cold (room temperature) and at warm conditions. A numerical methodology is presented to account for hole quality on the strength of alloy components. The approach is evaluated through a comparison of predictions with experimental results. The influence of machining and the resulting machined edge quality on the mechanical behavior of component parts is a concern that accompanies the development of all new structural materials. Machined edge quality comprises the surface integrity and process dependent defects that result from material removal. The surface integrity encompasses subsurface qualities (e.g. heat affected zone, subsurface cracks, etc)[3].

Due to the importance of this problem, the cut out effect has been studied by using analytical, numerical and experimental method in the past on metal and composite material. Zhao et al. [4] had been demonstrating the stress field around defects using Raman spectroscopy to map the stress distribution in the vicinity of discontinuities. Arola and McCain [3] study the influence of hole quality on the mechanical behavior and showed that the surface texture and stress concentration factor cannot be used for a reliable estimate of hole quality.

Monika et al [5] used finite element analysis to investigate the stress concentration in ASTM D 638 tension specimens and shows that it is possible to reduce the magnitude of the stress concentration factor by redesigning the specimen geometry without changing its overall size. Cesar, Peer and Alexander [6] developed an equations determining stress-concentration factors used in the analysis of loaded holes in mechanically fastened composites.

Experimental procedures

An experimental investigation is done on AL-Cu alloy. The chemical composition test results are listed in table (1) as obtained using the equipment of the laboratory of the Ministry of Industry and materials. The tensile test results of the alloy which show the mechanical properties are listed in table (2), and the tensile test behavior is shown in figure (2). The tensile tests were performed on (ASTM B 557-02a) tension specimens with central circular hole. The central circular hole of tension specimens were done using drill and punch at cold and warm working conditions with different selected diameters. At warm working conditions the tensile specimens were heated to a level below the alloy crystallization temperature. An electrical furnace was set on 210˚C until it reads out the set temperature; the specimens are then put inside the furnace for five minutes. They were then taken out of the furnace and the holes are introduced at that temperature using either drill or punch. The specimens for the cold working conditions are drilled or punched at room temperature.

The tensile tests for all specimens were performed at room temperature in the laboratory of the Ministry of Science and Technology.

Numerical analysis

Numerical analysis is performed using finite element method with aid of ANSYS-11 software. The specimens used in experimental test were draw here, and the two-dimensional plane stress six-node and twelve degree of freedom triangular linear elastic element was selected to model the tension specimens. Mesh generator were used. Figure (3) shows the finite-element meshes used to model the (ASTM B 557-02a) tension specimens with and without hole.

Due to the symmetric of the stress distribution about the transverse line passing through the center, andthe symmetry of the specimen geometry, only one quarter of the specimen is modeled. To prevent rigid body motion, the lines of the specimen center will be restrained from transverse displacement, when central hole presents, nodes on Line AB have zero displacement in the X-direction and are free to move in the Y-direction. Nodes on Line CD have zero displacement in the Y-direction and are free to move in the X-direction. Two finite element meshes will be used having different degree of refinement. The most refined mesh will be close to the hole. The number of nodes and elements in one quarter of the specimen with hole of 3.5 mm diameter are 600 and 503 respectively as shown in figure (4). In actual tensile tests, the specimen is clamped and pulled using a set of mechanical or hydraulic grips. To simulate and compare the numerical solution results with experimental test, the mechanical properties required in finite element analysis had been introduced from the experimental test results.

Biharmonic equation in polar coordinate using Michell solution represents one of the analytical solutions in which give a good results indicate the stress concentration factor due to the hole presents [7,8].

Results and Discussions

Experimental and numerical analyses were done to investigate the influence of cut out way on the elastic plastic behavior of Al-cu alloy. Thus tensile tests were performed on (ASTM B 557-02a) tension specimens with central circular hole. The central circular hole of tension specimens introduced using drill and punch at cold and warm working conditions; with (3.5, 4.25 and 6 mm) diameter. The experimental tests present the mechanical properties and the elastic plastic behavior while the numerical analyses show the stress distributions.

Figures (5) illustrate the variations of alloy mechanical properties and behavior with machining type at cold working condition, while figure (6) at warm working condition. The behaviors of stress strain relation in these two conditions are the same but differ in magnitude. As the hole diameter increase the mechanical properties of the alloy decrease. Tensile strength and yield stress with using bunch are less than that of using drill by 4% and 6% respectively due to rough hole surface present and greater residual stress take place. The elongation at maximum tensile strength of using punch is greater than that of using drill at cold working condition, while at warm working condition show vice versa. The fractures with using punch happen faster than that of using drill at low strain rate because the rough surface becomes a region of stress concentration.

Figure (7) represents the influence of machining working conditions on the alloy mechanical properties and behavior of using drill and punch respectively. The results show that the tensile strength and yield stress at cold working are greater than that at warm working conditions by 34% and 42% respectively. The elongation at maximum tensile strength of warm working conditions is higher by twice, while the fractures take place at lower stress and greater strain rate than that of cold working condition. The apparent stress concentration factor of each tensile specimen was determined experimentally from the ratio of tensile strengths of specimens without holes to that of specimens with holes as:

$$K_a = \frac{TS_O}{TS_H} \qquad \ldots (1)$$

Based on the results and using equation (1). The apparent stress concentration factor ranged from 1.19 to 2.9 with using drill, and from 1.25 to 3.39 with using punch, as shown in table (3).

von Mises nodal stress distributions as one of the numerical results analysis are shown in figures (9, 10, 11 and 12). Where the finite element analysis of each specimen; done at tensile strength load of the experimental test. The maximum von Mises stress present near the hole. The maximum von Mises stress was used to calculate the stress concentration factor and to identify the location that possibly initializes the fracture. The stress concentration factor can estimated as:

$$K = \frac{\sigma_{max}}{\sigma_{nom}} \qquad \ldots (2)$$

Where (σ_{max}) is the maximum nodal von Mises stress, and (σ_{nom}) is the average von Mises stress. Based on the numerical results and using equation (2). The stress concentration factors ranged from 2.13 to 2.39 as shown in table (3) and identical with [2,8].

Conclusions

The influence of cut out way on the elastic-plastic behavior of AL-Cu alloy was studied in the present work experimentally and numerically using finite element method with help of ANSYS-11. The following conclusions are drawn:

1. As the hole diameter increase the mechanical properties of the alloy decrease.
2. Tensile strength and yield stress with using bunch are less than that of using drill by 4% and 6% at cold condition, while at warm working condition by 34% and 42% respectively.
3. The elongation at maximum tensile strength of using punch is greater than that of using drill at cold working condition and vice versa at warm working condition.
4. The apparent stress concentration factor ranged from 1.19 to 2.9 with using drill, and from 1.25 to 3.39 with using punch.
5. Numerical analysis show the stress concentration factors ranged from 2.13 to 2.39 and identical with literatures.

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Table (1) AL-Cu Alloy chemical composition test performed in the laboratory of the Ministry of Industry and Materials.

Item	Percentage
AL	90.24
Si	0.25
Mg	0.012
Cu (PPm)	13

Table (2) Tensile test (mechanical properties) results of AL-Cu Alloy.

E (Gpa)	**73.8**
e (%)	**2.28**
σ_y (Mpa)	**105**
TS (Mpa)	**114.2**
Poisson ratio	**0.337**

Table (3) Experimental and numerical results summary

	Drill					
	Cold			**Warm**		
d (mm)	**3.5**	**4.25**	**6**	**3.5**	**4.25**	**6**
σ_y (MPa)	**82**	**68.6**	**50**	**42.2**	**38.3**	**32**
TS(MPa)	**95.2**	**83.4**	**64.9**	**56.8**	**50.7**	**39.1**
e%	**2.58**	**2.47**	**1.83**	**9.15**	**7.16**	**4.79**
K_a	**1.19**	**1.37**	**1.75**	**2.01**	**2.25**	**2.9**
K	**2.39**	**2.22**	**2.13**	**2.37**	**2.23**	**2.13**

	Punch					
	Cold			Warm		
d (mm)	3.5	4.25	6	3.5	4.25	6
σ_y (MPa)	77	64	48	40.1	35.3	29
TS(MPa)	91.3	80.5	64	48	42.2	33.6
e%	3.42	2.49	1.92	8.2	6.12	3.07
K_a	1.25	1.41	1.78	2.37	2.7	3.39
K	2.37	2.21	2.16	2.36	2.23	2.13

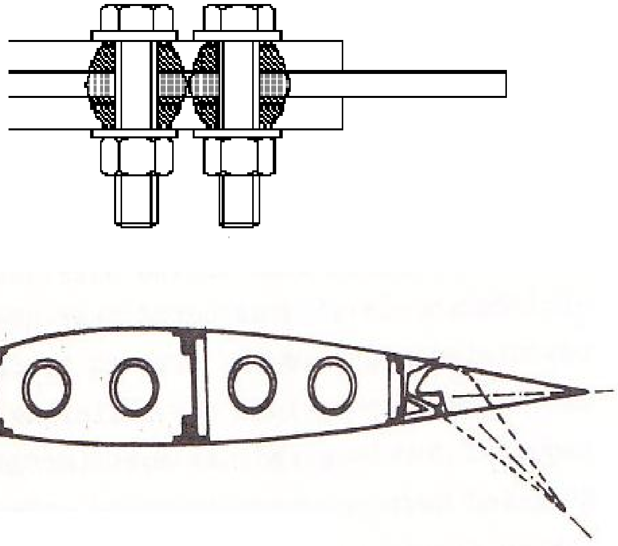


Figure (1) Applications of cut out [1,2].

(a)

(b)

Figure (2) Tensile test specimens (a-before test, b-after test).

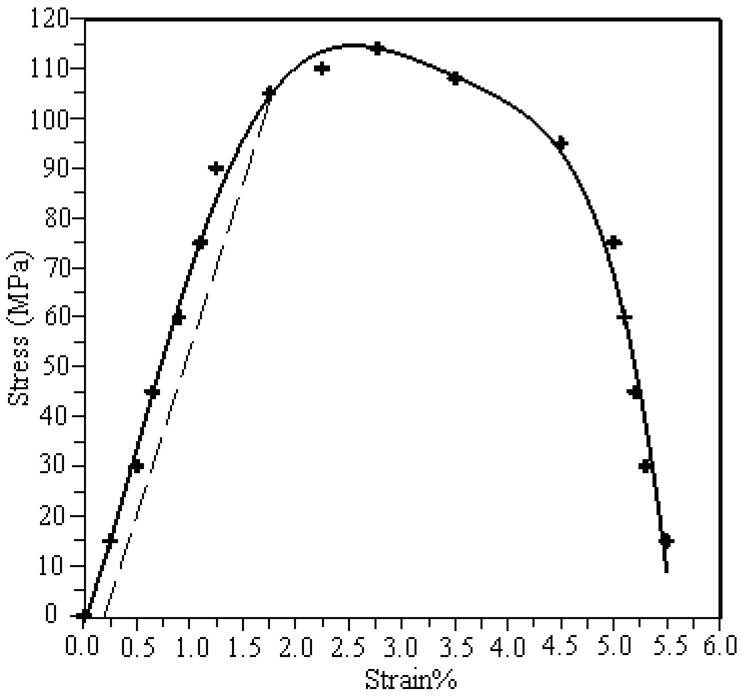
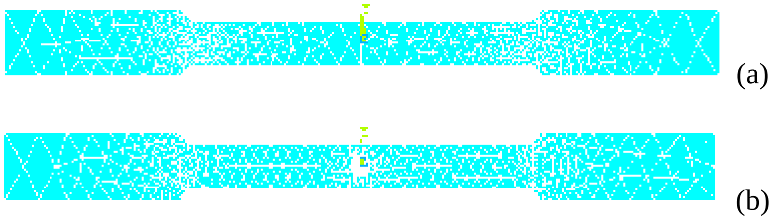


Figure (3) Tensile test results of AL-Cu alloy tension specimen.


(a)

(b)

Figure (4) Finite-element meshes (a-without hole, b-with hole).

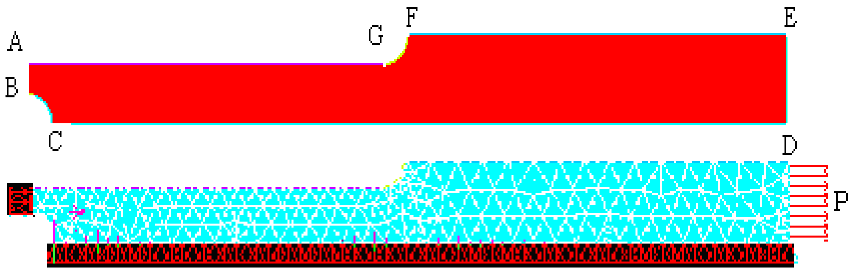


Figure (5) One quarter of the specimen model in finite element method.

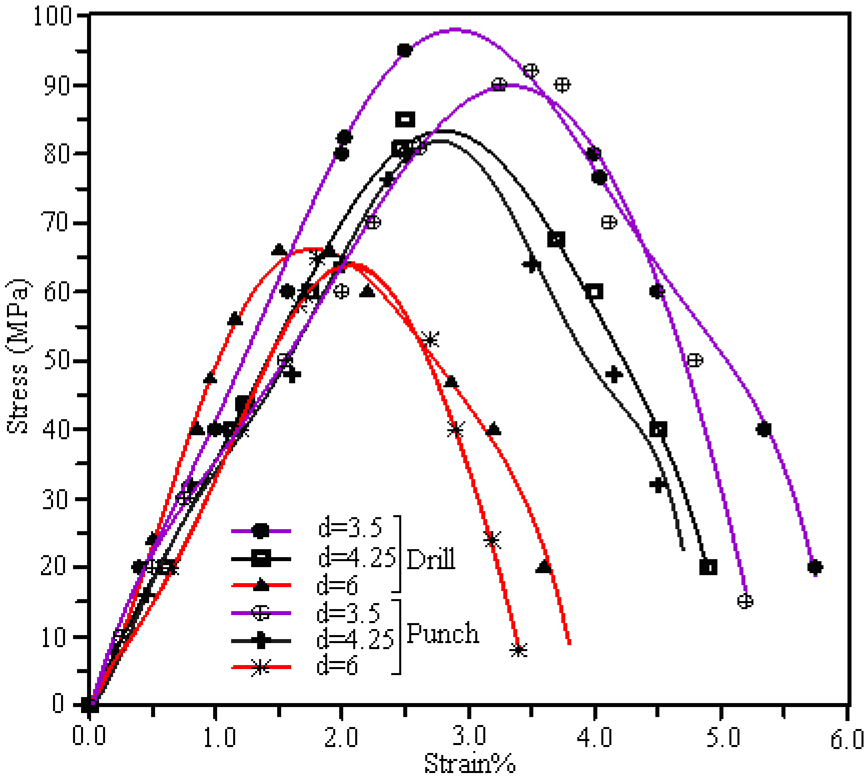


Figure (6) Stress-strain variation with machining type at cold working conditions.

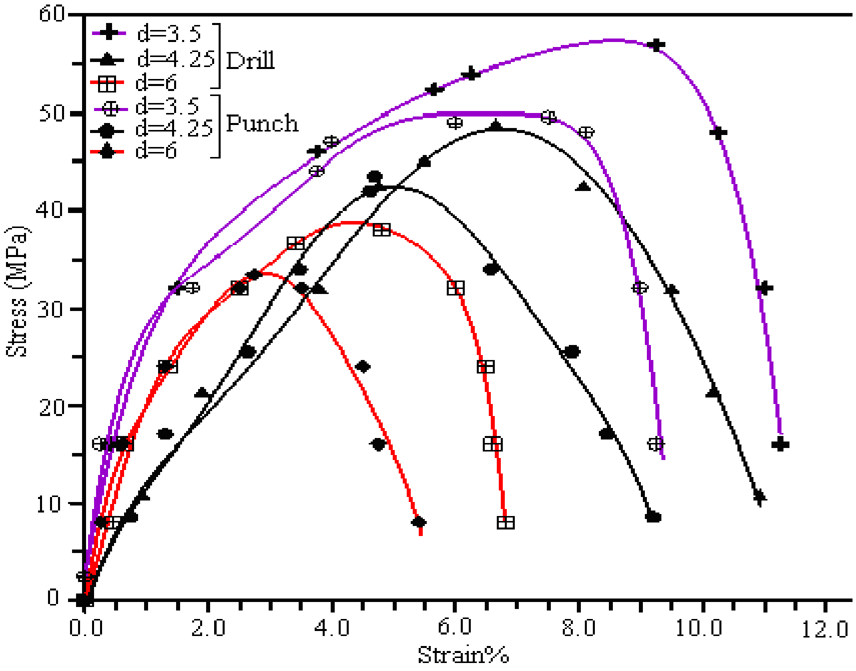


Figure (7) Stress-strain variation with machining type at warm working conditions.

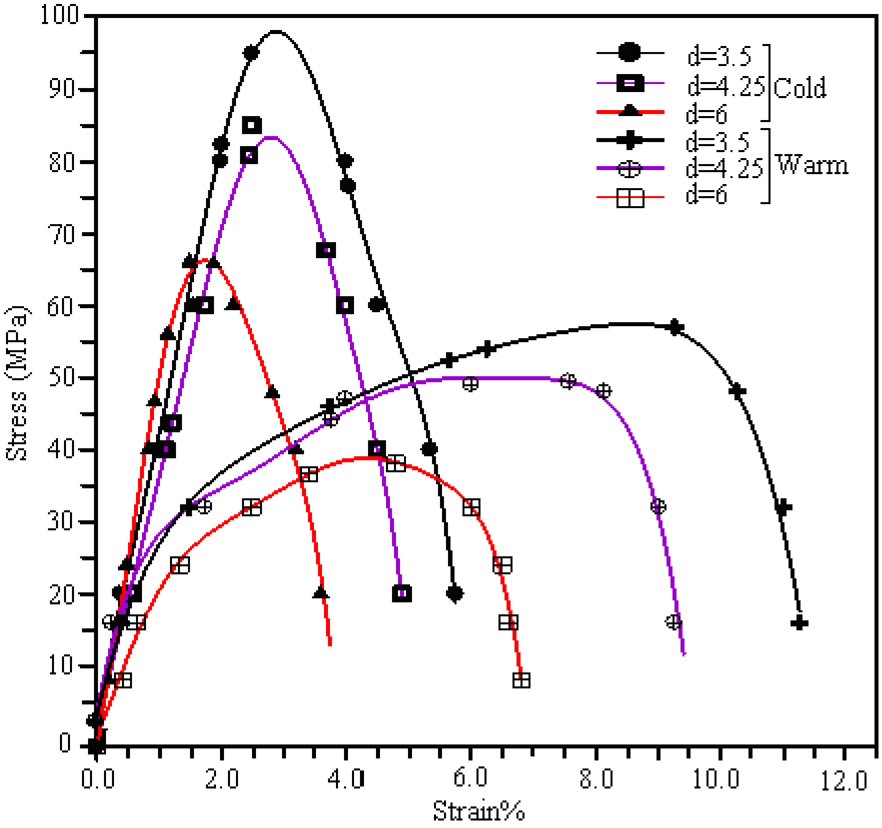


Figure (8) Stress-strain variation with working conditions using drill.

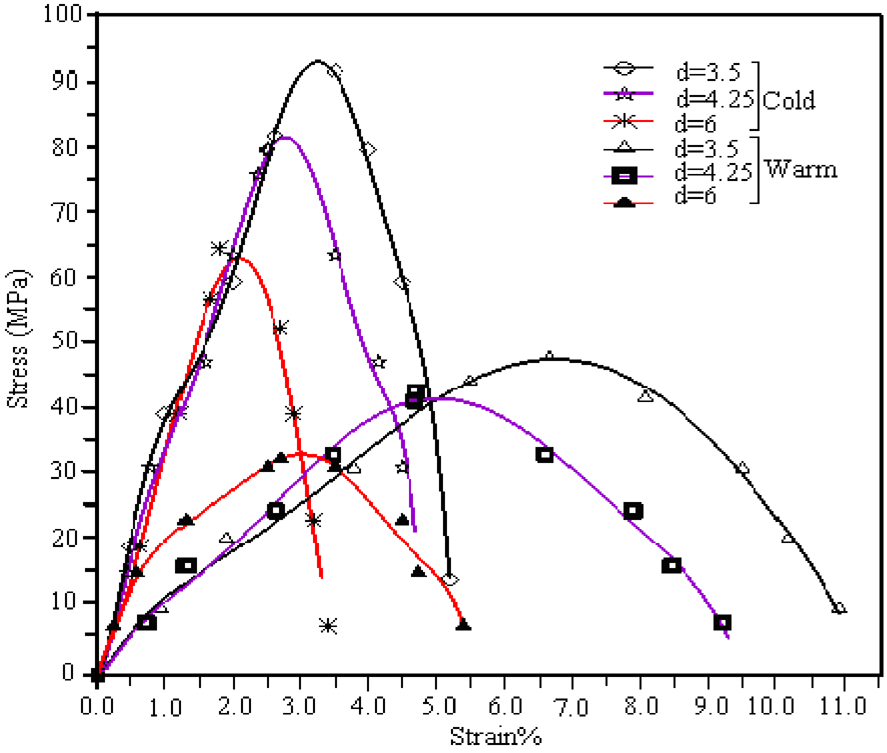
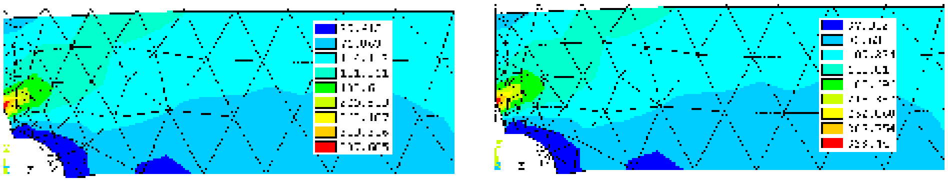
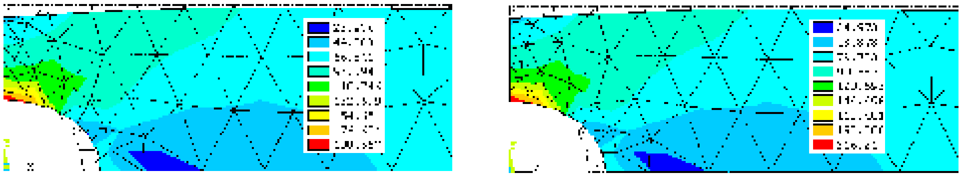


Figure (9) Stress-strain variation with working conditions using punch.



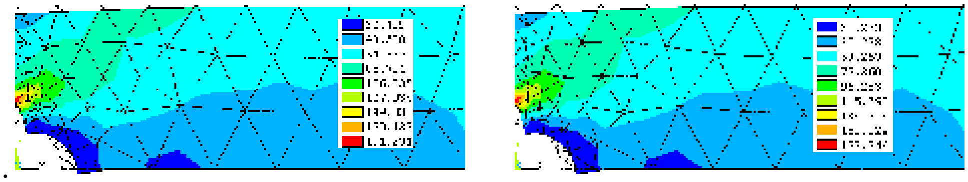
a-drill b-punch

Figure (10) von Mises stress distribution at cold condition (d=3.5 mm).



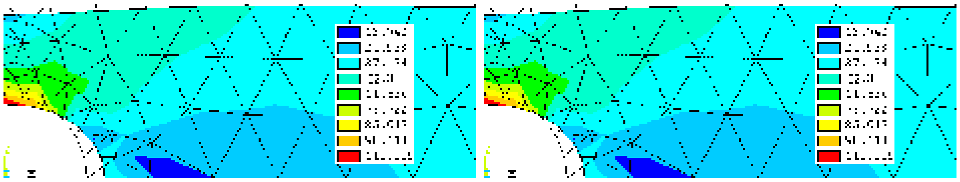
a-drill b-punch

Figure (11) von Mises stress distribution at cold condition (d=6mm)



a-drill b-punch

Figure (12) von Mises stress distribution at warm condition (d=3.5mm)



a-drill b-punch

Figure (13) von Mises stress distribution at warm condition (d=6mm)