ISSN 1411 - 9471

Volume 8 Nomor 3, September 2008

Jurnal TEKNIK MESIN

TERAKREDITASI
Nomor : 43/DIKTI/Kep/2008

JURNAL TEKNIK MESIN	Volume 8	Nomor 3	Halaman 151 - 226	SURABAYA September 2008	ISSN 1411-9471

JURNAL TEKNIK MESIN

ISSN 1411 – 9471, TERAKREDITASI Nomor : 43/DIKTI/Kep/2008

Jurnal Teknik Mesin terbit tiga kali setahun pada bulan Januari, Mei dan September.
Berisi tulisan yang diangkat dari hasil penelitian dan kajian analitis kritis di bidang Teknik Mesin.

Jurnal Teknik Mesin diterbitkan oleh
Jurusan Teknik Mesin FTI ITS

Alamat Redaksi
Jurusan Teknik Mesin FTI ITS
Kampus ITS Sukolilo, Surabaya 60111
Telp. 031- 5922941, 5946230, Fax. 031-5922941

E-mail : jurnalme@me.its.ac.id,
jurnalme@yahoo.co.id
Website : www.me.its.ac.id/Data/jurnal.html,
jurnalme.bravehost.com

Penyunting menerima sumbangan tulisan yang belum pernah diterbitkan dalam media lain.
Naskah diketik mengikuti Persyaratan Naskah Jurnal Teknik Mesin
seperti tercantum pada bagian dalam sampul belakang Jurnal Teknik Mesin.

Jurnal TEKNIK MESIN

Volume 8 Nomor 3, September 2008

ISSN 1411 – 9471, TERAKREDITASI Nomor : 43/DIKTI/Kep/2008

KATA PENGANTAR

Pada penerbitan kali ini, JTM berhasil memuat artikel selain dalam jumlah yang banyak, juga dari beragam lingkup studi dan asal peneliti. Delapan artikel yang berhasil diproses secara merata tersebar dalam tiga kelompok lingkup studi, yaitu: material/metalurgi, desain, manufaktur, dan konversi energi. Dari delapan artikel, dua berasal dari peneliti dalam ITS dan selebihnya berasal dari peneliti luar ITS (Universitas Katolik Parahyangan, Universitas Indonesia Depok, Universitas Lampung, Universitas Muhammadiyah Sidoarjo, Universitas Diponegoro, Politeknik Perkapalan Negeri Surabaya).

Dewan penyunting mengucapkan terima kasih kepada para pengirim artikel dan penyunting ahli yang telah memberi sumbangan pada kualitas jurnal ini. Kami juga berterima kasih kepada seluruh pelanggan kami yang telah memanfaatkan JTM sebagai bahan rujukan dan inspirasi dalam penelitiannya.

Kami mengajak para peneliti dan praktisi bidang Teknik Mesin untuk menulis artikel pada Jurnal Teknik Mesin ini (terbit setiap Januari, Mei, dan September). Artikel anda akan dirujuk oleh pelanggan kami dari seluruh penjuru Indonesia.

Akhirnya kami berharap semoga artikel-artikel berkualitas dalam jurnal ini dapat bermanfaat bagi pembaca dan memberikan inspirasi dalam pengembangan teknologi di bidang rekayasa mesin.

Dewan Penyunting

Experimental Method for the Determination of Stress Concentration Factors of Stepped-Shafts of Circular-to-Square Cross Section under Pure Torsion

Jamiatul Akmal & Asnawi Lubis
Department of Mechanical Engineering, University of Lampung
Gedung H Fakultas Teknik, Jalan Professor Sumantri Brojonegoro
Gedongmeneng, Bandar Lampung, 35145
Telp: (0721) 7479221, 701609 ext. 221, Fax: (0721) 704947
E-mail: asnawi-lubis@unila.ac.id

Received March 24th, 2008; correction received August 27th, 2008; approved September 11th, 2008

Abstract

Shaft is a machine element with main function for power transmission. Shaft is often needed in stepped form (change in cross-section). For a non-smooth shaft (stepped shaft), the elementary stress equations are no longer hold for calculating the actual stress as the stress would be higher than the nominal stresses. To relate the maximum stress at the discontinuity with the nominal stress calculated using the elementary stress equation, a factor is needed which is called stress concentration factor (SCF). This paper aims to present an experimental result of stress concentration factor of stepped shaft of circular-to-square cross-section under pure torsion. The results show that stress-concentration factor of stepped shaft of circular-to-square cross-section is slightly higher than corresponding stepped-shaft of circular-to-circular cross section.

Keywords: *stepped-shafts, circular-to-square cross-section, stress-concentration factors, strain gages, pure torsion.*

Shaft is a machine element with main function for power transmission. Shaft is often needed in stepped form (change in cross-section). Example is a rotated shaft with square shoulder for the seat of bearing. In such, the shaft could be subjected to combined loading of axial, bending, and torsion.

If a shaft is smooth, the resulting stress due to loading can be computed using the elementary stress equations. This stress is called nominal stress. For a non-smooth shaft (stepped shaft), the elementary stress equations are no longer hold for calculating the actual stress as the stress would be higher than the nominal stresses. To relate the maximum stress at the discontinuity with the nominal stress calculated using the elementary stress equation, a factor is needed which is called stress concentration factor (SCF). The magnitude of this factor depends on diameter ratio, shape and area of cross-section, radius of fillet and types of loading (axial, bending, torsion, or their combination).

Stress concentration factors for a stepped shaft of uniform cross-section can be found in many standard textbooks of mechanics of materials [1,2,3]. Until now, the most complete source of graph of stress concentration factors for various geometry of shaft, bar, and plat is a compendia by Peterson [4]. In this compendia, stress concentration factor (K_t) for stepped shaft of uniform cross-section are plotted as a function of non-dimensional geometry. Today state of the art modern literature are also still using the Peterson's graph for analyzing the stepped shaft of uniform cross-section, see for example, Kang, et al [5]. Pan, et al [6] used the Peterson's graph to analyze the torsion vibration of stepped shaft. Kim and Kim [7] used the same graph to analyze the stresses at the stepped shaft subjected to axial tension.

A graph for stepped shaft of circular-to-square cross-section is not available in the compendia of stress concentration factors by Peterson [4]. Baker [8] carried out a finite element study using ALGOR version 3.18 to obtain the static characteristic of stepped shaft of circular to square cross-section subjected to combined loading of static bending and torsion. To analyze a stepped shaft of circular-to-square cross-section, it is common to apply the graph for stepped shaft of uniform circular cross-section of equivalent cross-sectional area to square [9]. This was usually done because similar graph for stepped shaft of circular-to-square cross-section was not available either in textbooks or in today state of the art modern literature. However, current finite element study on stress concentration factor of stepped shaft of circular-to-square cross-section under axial tension, pure bending and pure torsion were presented in a series of papers by Lubis and Akmal [10,11,12]. The present paper present an experimental validation of stress concentration factors of a shaft of circular-to-square cross-section subjected to static pure torsion.

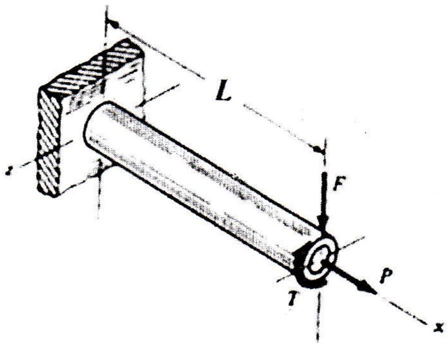

Figure 1. A circular shaft subjected to combined loading of axial, bending and torsion.

STRESS CONCENTRATION FACTORS

Shaft is an important element in machineries. Shaft is usually has function for power transmission. Shaft can be found as square cross-section as well as circular cross section. However, majority of shaft are circular cross-section as its main function is for power transmission, whereas, shaft of square cross-section is usually only used for supporting load.

Circular shaft is a rotating element where other elements such as gears and pulley are mounted. Such a shaft could be subjected to axial (tension or compression), bending, torsion, or their combination as shown in figure 1.

In particular application, a shaft of non-uniform area of cross section (stepped shaft) might be used. Change in area of cross-section of stepped shaft results in stress concentration at the discontinuity. In order to reduce the effect of stress concentration at the region of change in cross-section, fillet of radius r is usually applied as shown in figure 2.

The ratio of maximum stress at a critical point to the nominal stress is called stress concentration factor (SCF). Stress concentration factor of circular stepped shaft has been given by Peterson [4]. The magnitude of this factor is a function of non-dimensional parameter D2/D1 and r/D1. Stress concentration factor, Kt, can be written as:

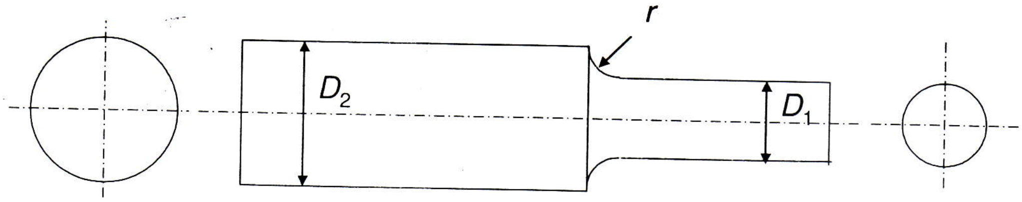

Figure 2. Circular stepped shaft with shoulder or radius *r*.

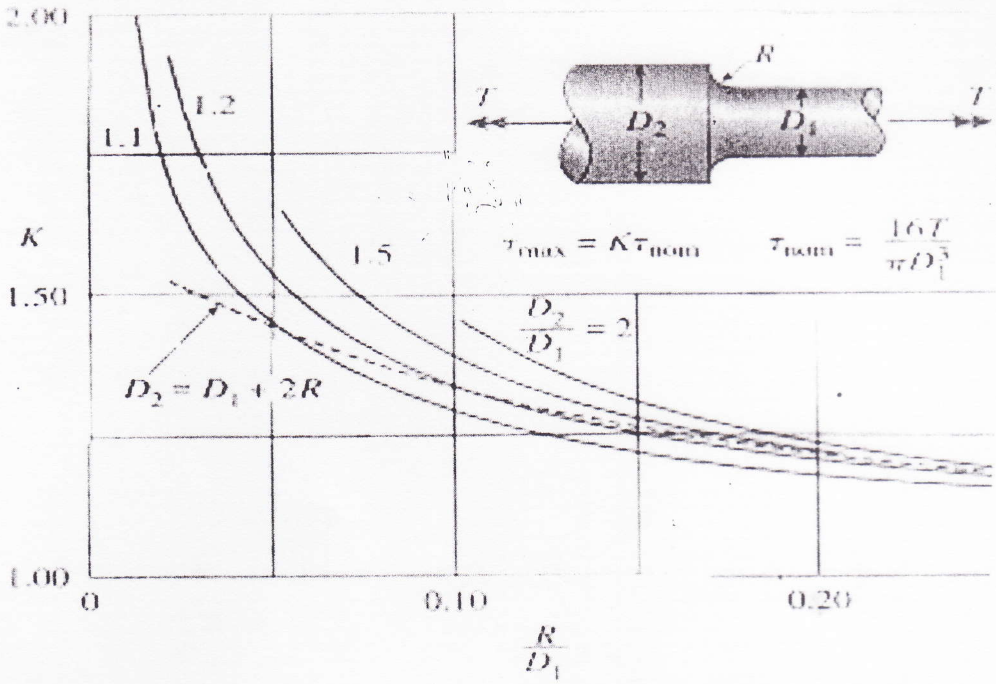

Figure 3 Stress-concentration factors for circular stepped-shaft under torsion [Peterson, 1974].

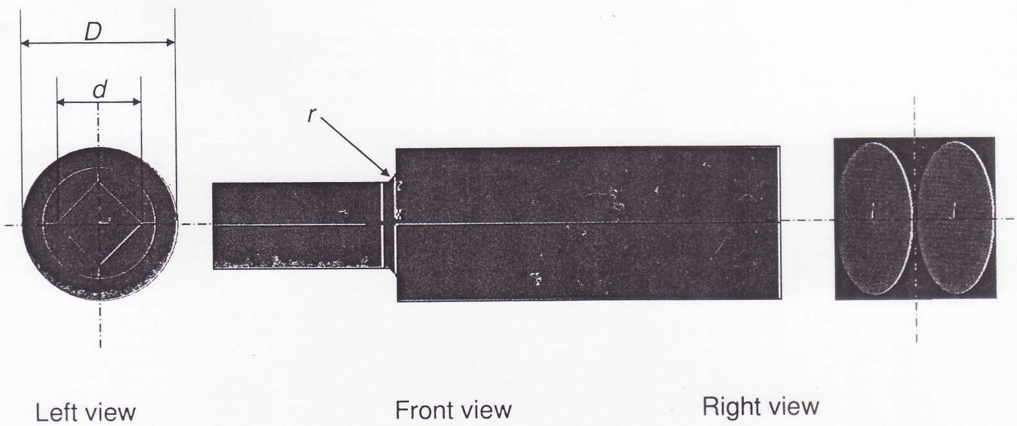

Figure 4. Stepped shaft of circular to square cross-section.

$$K_t = \frac{\sigma_{max}}{\sigma_{nom}} \text{; For normal stress} \quad (1a)$$

$$K_{ts} = \frac{\tau_{max}}{\tau_{nom}} \text{; For shear stress} \quad (1b)$$

Where, for circular cross section the nominal stress is given by:

$$\sigma_{nom} = \frac{4P}{\pi D_1^{\ 2}} \text{; For axial load} \quad (2)$$

$$\sigma_{nom} = \frac{32M}{\pi D_1^{\ 3}} \text{; For bending load} \quad (3)$$

$$\tau_{nom} = \frac{16T}{\pi D_1^{\ 3}} \text{; For torsian load} \quad (4)$$

Figure 3 shows a typical graph of stress concentration factor for circular stepped-shaft under twisting moment. The graph was taken from a book of "Stress Concentration Factor" by Peterson [4]. Similar graph for axial and bending load can be obtained from the same book.

In the book of Peterson, it cannot be found a graph of stress-concentration factor for a stepped shaft of circular-to-square cross-section (Figure 4). In fact, stepped shaft of this form can be found in practice, such as, the output low speed reducer at mill and diffuser station in sugar cane industry [9]. This paper aims to presents an ad hoc experimental result of stress concentration factors of stepped shafts of circular to square cross-section under pure torsion.

EXPERIMENTAL SET-UP

Figure 5 shows the experimental set-up to determine the stress concentration factors of a stepped shaft of circular to square cross-section under pure torsion. The shaft was 245 mm length with the length of square part of 105 mm included fillet. The diameter of the circular cross-section (D) was 45 mm and the diagonal of the square section (d) was 30 mm leading to the value of non-dimensional parameter D/d =

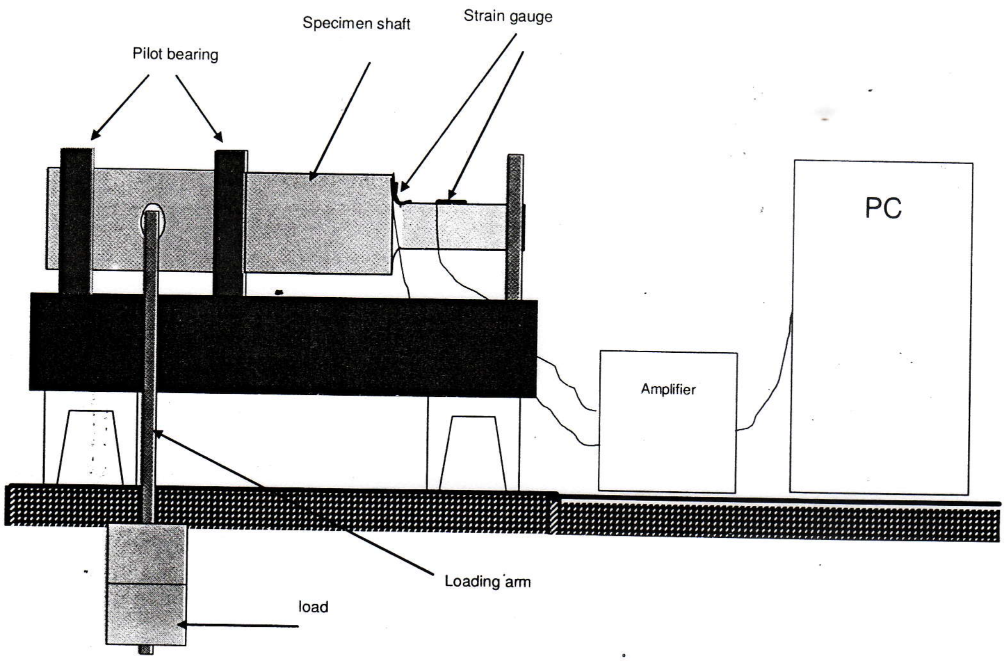

Figure 5. Experimental set-up to determine SCF of stepped shaft of circular to square cross-section.

1.5. The radius of the filled (r) was 4.5 mm leading to the value of non-dimensional parameter r/d = 0.15. See Figure 4 for nomenclature of the shaft. The load was applied as shown and the pure torsion effect was obtained.

Strain gages were placed on the fillet and square side which are connected to data acquisition system. The type of strain gage used [see Figure 6(a)] was FLA-5-11 with gage length, resistant, and gage factor of 5, 120±0.3 Ω, and 2.11 respectively. The data acquisition system consists of wheat-stone bridge integrated in amplifier system as shown in Figure 6(b). The output of the amplifier was then recorded and read by computer.

Three shafts of the same geometries and material properties were tested. Every specimen was loaded (as shown in Figure 5) three times by weighting load of 11, 18, and 25 kg. With the loading arm of 1.5m length and the assumption of 9.81 m/s^2 gravity acceleration, the torsion applied was equivalent to 161.7, 264.8, and 367.5 N.m respectively.

RESULTS & DISCUSSION

Stress concentration factors can be computed using equation (1b). In this analysis, it was assumed that the material of the shaft is still linear elastic. Therefore, stress-concentration factors can be computed as a direct comparison of shear strain in the fillet to the shear strain in the square side.

Table 1, 2, and 3 present stress concentration factors of specimen 1, 2, and 3 respectively. The computed strains in the Tables were obtained by subtracting the strain of zero load from the strain of non zero load, i.e., 11, 18, and 25 kg respectively. The stress concentration factors were then obtained by direct comparison of computed strains at fillet side and square side. For specimen no.1, stress concentration factor was about 2.39. For specimen no.2 and 3, stress concentration factor was about 1.46 and 1.58 respectively. The results of specimen 2 and 3 seem to be in good agreement. However, the result for specimen no. 1 shows a marked different. It was suspected that this marked different results from difficulty and inaccuracy in placing the strain gage, particularly on the filled side.

For the geometry considered in this study, stress concentration factors read from the well-known Peterson graph for stepped-shaft of circular cross-section [Figure 3], the value of stress concentration factor was about 1.29. By this comparison, it seems that the result for specimen 2 and 3 of this study is reasonable; however, result for specimen no.1 needs further assessment.

CONCLUSIONS

Experimental investigation on the stress concentration factors of stepped shaft of

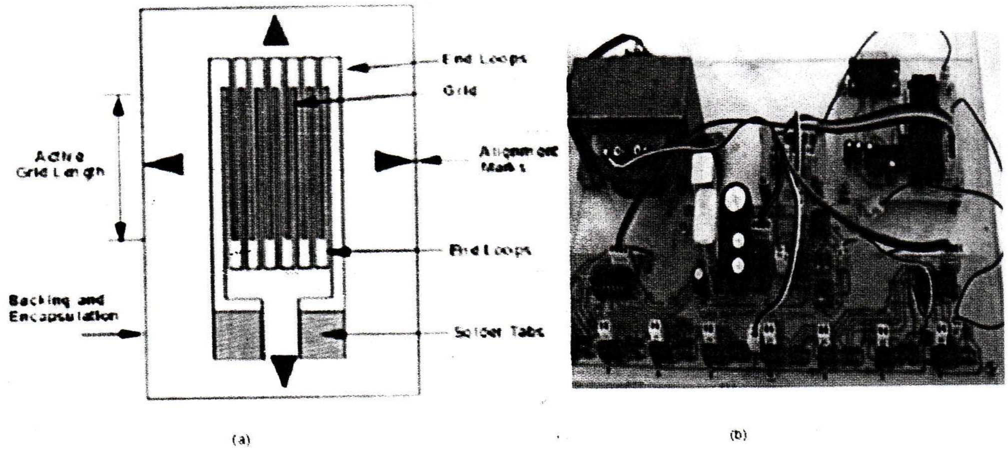

Figure 6. (a) resistant-type strain gage, (b) Amplifier.

circular to square cross-section under pure torsion shows a higher value than those for stepped shaft of circular to circular cross-section, as expected! Two of the specimen tested for stress concentration factors shows a good agreement each other and close to the

Table 1. Stress Concentration Factor for Specimen No.1

Load (kg)	Strain read by computer (μ strain)		Computed strain (μ strain)		Stress Concentration Factor (SCF)
	Fillet	**square**	**Fillet**	**square**	
0	2887,822	3570,0443	-	-	-
11	2578,916	3431,6121	-308,906	-138,432	2,231461
18	2444,652	3383,5458	-443,171	-186,499	2,376269
25	2370,629	3368,1643	-517,193	-201,880	2,561884
		Average			2,389871

Table 2. Stress Concentration Factor for Specimen No.2

Load (kg)	Strain read by computer (μ strain)		Computed strain (μ strain)		Stress Concentration Factor (SCF)
	Fillet	**Square**	**Fillet**	**Square**	
0	2154,438	3858,33407	-	-	-
11	2056,072	3794,03333	-98,3659	-64,3007	1,529779
18	1958,434389	3722,289444	-196,004011	- 136,0446	1,440733
25	1905,007	3681,83709	-249,431	-176,497	1,413233
		Average			1,461249

Tabel 3. Stress Concentration Factor for Specimen No.3

Load (kg)	Strain read by computer (μ strain)		Computed strain (μ strain)		Stress Concentation Factor (SCF)
	Fillet	**Square**	**Fillet**	**square**	
0	1572,113	3377,03127	-	-	-
11	1345,344	3241,57654	-226,77	-135,455	1,674136
18	1240,272	3172,53765	-331,842	-204,494	1,622749
25	1185,878	3112,27732	-386,236	-264,754	1,458847
		Average			1,585244

stress-concentration factor of equivalent stepped shaft of circular to circular cross-section. However, result for specimen no.1 shows a marked higher value of stress concentration factors, about two times others. This different is suspected as a result of inaccuracy when placing the strain gages on the specimen, especially in the fillet side. By comparison with the well-known Peterson graph, it was concluded that the experiment has given expected results.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Directorate General of Higher Education (DIKTI) of the National Education Department of Indonesia for providing fund through Fundamental Research Grant under contract No. 010/SP3/PP/DP2M/II/2006.

REFERENCES

[1] Benham, P.P., Crawford, R.J., & Armstrong, C.G., 1996, *Mechanics of Engineering Materials*, second edition. Longman Group Limited, UK

[2] Timoshenko, S.P., 1998, *Mechanics of Materials*, third SI edition. Stanley Thornes (Publisher) Limited.

[3] Cook, R.D., and Young, W.C., 1999, *Advanced Mechanics of Materials*, second edition. Prentice-Hall International Inc.

[4] Peterson, R.E., 1974, *Stress Concentration Factors*. John Wiley & Sons, Inc.

[5] Kang, M.K., Huang R. & T. Knowless, 2005, "Torsional Vibration of Circular Elastic Plates with Thickness Steps", *IEEE Transactions on Ultrasonics, Ferroelectric, and Frequency Control.*

[6] Pan, J.Q., Pan, J., Ming, R.S., & Lin, T., 2000, "Three-Dimensional Response and Intensity of Torsional Vibration in a Stepped Shaft", Journal of Sound and Vibration, Vol. 236, pp. 115 – 128.

[7] Kim, Y.Y. and Kim, J.H., 1995, "Stress Analysis of a Stepped Shaft under Remote Tension", *Quarterly Journal of Applied Mathematics*, Vol. 48, pp. 517 – 530.

[8] Baker, D.A., 1999, "A Finite Element Study of Stresses in Stepped Splined Shafts and Partially Splinned Shafts under Bending, Torsion, and Combined Loadings". *MSc Thesis*, Virginia Polytechnic Institute and State University

[9] Yusron, N., 2004, "Fracture Analysis of a Square Shaft Output Low Speed Reducer of Mill and Diffuser Station of Sugar Cane Industry of PT Bunga Mayang of North Lampung (In Indonesia)", *Student Job Training Report*, Department of Mechanical Engineering, University of Lampung.

[10] Lubis, A. and Akmal, J., 2006, "Stress Concentration Factors of Stepped Shafts of Circular-to-Square Cross-Section under Axial Tension", *Proceeding Seminar Nasional Teknologi Industri (TEKNOIN), Universitas Islam Indonesia*, Yogyakarta.