Global Journal of Engineering and Technology Review
Journal homepage: http://gjetr.org/
Global Journal of Engineering and Technology Review 1 (1) 49 – 56 (2016)

Effect of Notching Face on Fracture Toughness of Green Metal Powder Compacts

A. A. Alabi [1]*, S. M. Tahir [2], N. I. Zahari,[3] M. A. Azmah Hanim[4] and M.S. Anuar[5]

[1,2,3,4] Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor,
[5] Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

---

ABSTRACT

Objective – To predict the failure of a powder compacted component, it is important to understand how its physical and mechanical properties varies in its green state. The variation of fracture toughness of iron and copper powder compact with compaction pressures, along the longitudinal axes of their green compacts is presented in this paper
Methodology/Technique – Mode I fracture toughness, KIC, was determined for specimens compacted uniaxially, using the diametrical compression technique by comparing the effect of notching a specimen on its top surface against notching it on the bottom
Findings – Results showed that specimens notched on the top surface had higher KIC values for both powders at all compaction pressures. The pair of KIC values was more stable for the copper compacts than for iron compacts
Novelty – This is the work that shows the need to always specify the notched surface while stating KIC for metal powder compacts.

Type of Paper: Empirical

Keywords: Green Compacts; Uniaxial Compaction; Diametrical Compression Technique; Fracture Toughness

---

1. Introduction

The strength and toughness of powder metallurgy (PM) components are very important properties in determining their area of usage and their service life. Though post-forming treatments such as sintering are known to increase the properties of PM components, the quality of the green strength determines the final properties of a compact(Jonsén, Häggblad, & Sommer, 2007). To produce powder compacts with high green strength, one must strive to achieve high density homogeneity and minimal crack formation. These can be achieved by carefully choose and control factors such as; powder production, powder handling and powder pouring, powder particle sizes, compaction technique, compaction pressure, compaction rate, ejection rate,

* Paper Info: Revised: July, 2016
Accepted: November, 2016
* Corresponding author:
E-mail: abdulmm2001@gmail.com
Affiliation: Faculty of Engineering, Universiti Putra Malaysia, Malaysia

friction between die wall and powder, lubricant and lubrication technique, and post-compaction handling(Lenel, 1980). Cracks in engineering parts and structures are results of flaws in materials, defect from manufacturing processes, or discontinuities. A crack creates a weak link in the internal structure of a component, which under load, stress or aggressive environment easily propagates leading to failure (Norman, Alex, & Xici, 1994). Powder compacts are products of a well-established sequence of events which include powder transfer and die filling, compaction, ejection and post-ejection handling. Defects or cracks can form in the compact at any stage in this sequence but are more likely during compaction, when inter-particle bond formed are weak or not formed, and during ejection, when the formed bonds are broken. Cracks in metal compacted components are the main cause of fracture failure during service. One parameter used by researchers and in industries to predict the ability of a component to resist fracture failure in the presence of crack is fracture toughness, K_c. Many techniques have been used to determine the fracture toughness of materials used in powder compaction. These methods are divided into two categories: one uses the notches and induced cracks; and the other studies the behavior of micro-cracks induced by indenter hardness testers such as Knoop or Vickers(Degnan, Kennedy, & Shipway, 2004)(Varin, Zbroniec, Czujko, & Song, 2001). The diametrical compression technique, also known as the Brazilian Disk test belongs to the former. In 1995, the International Society for Rock Mechanics (ISRM) Commission on Testing Methods accepted a method proposed by R.J. Fowell for the determining mode I fracture toughness for rock materials. The unique feature of the method was the well-defined chevron notch at the centre of the rock specimen (Rowell, 1995). It is the usually sorted alternative by researchers whose test specimens are cylindrical in their as-produced form, such as compacts and tablets but are difficult to be made to conform to the ASTM standard specimen geometry for tensile test(Procopio, Zavaliangos, & Cunningham, 2003). Because of the peculiar nature of powders and the relatively smaller diameters of powder compacts, this method has been modified and adapted in different form to determine fracture toughness. This technique has been used to determine the tensile strength and fracture energy of iron powders without notching the specimen (Jonsén et al., 2007). It has also been used to determine fracture toughness of iron powder with straight notch across the diameter of the specimen(Degnan, Kennedy, et al., 2004). The behaviour of loose powder compacted in a rigid, column-like die can be divided into three stages: (1) The first involve the rearrangement of the powder particles, also known as packing. (2) The elastic and plastic deformation of the particles. The ductility of the powder is the major factor that affects the amount of plastic deformation in any powder. In metal powders, plastic deformation cause adjacent powder particles to form local weld and also to work harden. (3) The final is where local welds formed in during plastic deformation, and particles of the powder are broken (Seeling & Wulff, 1946). These stages have been used to explain why the density of powder in a column-like die increase with pressure(Anand & Mohan, 2012), and why the porosity decrease with pressure. It has also been mentioned that the compaction pressure is not uniformly distributed along the length of the column in uniaxial compaction(Lenel, 1980). The hardness values of powder compacted uniaxially has been reported to also vary along longitudinal sections. These imply that the density of a powder compact, its porosity, and its hardness differs at different point along its longitudinal section. Researches that studied the fracture toughness of different powders, ceramics, and particulate composite materials, have not look at the likelihood of fracture toughness varying in a similar manner. One of the reasons might be the difficulty that will be involved in trying to examine the variation of fracture toughness at different points along the longitudinal section of a compact using the diametrical compression. This variation can be inferred by studying it at the two surfaces of the compact, see Figure 1. This research aim to investigate the effect of notching the two faces of green metal compacts, one at a time, on mode I fracture toughness.

2. Materials and Methods

2.1 Materials

In this study two metal powders were cold compacted, uniaxially, in a rigid die. The powders are atomized iron powder, Hoganas ASC 100.29, and copper powder. They were obtained from Sumitomo Sintered Sdn. Bhd. Malaysia. Some of their properties are given in Table 1 and Table 2.

Table 1. Properties of Iron Powder

Chemical Properties	C = 0.002%, O = 0.13%, Fe is base
Apparent Density, g/cm^3	2.98
Hall Flow Rate, sec,/50g	25
Green Density (GD) @ 600 MPa, g/cm^3	7.13
Particle Size Distribution	<45μm = 23.7%, <75 μm = 27.4%, <150 μm =41.7%, <180 μm =6.6%, >180 μm = 0.6%, >212 μm = 0%

Table 2. Properties of Copper Powder

Chemical Properties	Sn ≤ 0.1%, Pb = 0.003%, Loss in H = 0.16 %, Cu = 99.7%
Apparent Density, g/cm^3	3.51
Hall Flow Rate, sec,/50g	22
Green Density (GD) @ 600 MPa, g/cm^3	-
Particle Size Distribution	<45μm = 73.58%, >45μm = 26.10%, >75 μm = 0.20%, >106 μm =0.03%

2.2 Methods

In this study two metal powders were cold compacted, uniaxially, in a rigid die. The powders are atomized iron powder, Hoganas ASC 100.29, and copper powder. They were obtained from Sumitomo Sintered Sdn. Bhd. Malaysia. Some of their properties are given in Table 1 and Table 2.

2.2.1 Compaction and Notching

The uniaxial compaction and notching take place concurrently inside a 20 mm diameter rigid SPECAC pellet die. The die comprised basically, the mold, the plunger, and identical top and bottom punches. The compaction process involves a top-to bottom press, the compacting pressure was applied to the powder in the die from the top via the loading head of an Instron 3382 Universal Tensile Tester controlled by Bluehill Software. Four compacting pressures ranging from 206.87 to 302.36 MPa, at equal intervals were used in this study. A constant mass of powder, 15g, was used for all compacts produced. The final mass of each sample was measured again after compaction. The mass difference for the iron powder compacts was about 2% while that of the copper powder compacts was about 3.3%. The final height of the compacts were also measured and recorded.

To produce a compact with a straight notch on the bottom surface; the powder in the cavity was pressed against a thin razor blade at the bottom of the die. The razor blade was pressed into the powder from the top to make notch on the top surface. The combined compaction and notching process was carried out on a universal tensile testing machine. The rate of compaction was 2mm/min while the ejection was at 5 mm/min. A total of 80 notched compacts were produced and examined, 5 compacts for each experimental condition, i.e. compaction pressure and notching surface.

2.2.2 Diametrical Compression

Each of the 80 green notched compacts produced was compressed diametrically on a 5KN capacity Istron Universal Tensile Tester at a rate of 0.05 mm/min. Each cylindrical compact was loaded on its curved surface with the notch parallel to the direction of load application. The maximum force before fracture was recorded. Using Equation 1 was used to calculate the Mode I fracture toughness for compacts.

$$K_{IC} = \frac{2.24}{DT}\frac{P_f\sqrt{c}}{\sqrt{\pi}} \qquad (1)$$

Where

D = diamter of compact,
T = thickness of compact,
P_f = maximum load at failure, and
c = depth of notch.

2.2.3 Microstructural Analyses

In order to study the arrangement of the powder particles in the compacts, the microstructure of the unnotched compacts were observed using optical microscope and the Field Emission Scanning Electron Microscope. Unnotched compacts were produced from 15 g of powders compacted at the different selected pressures. These compacts were cut along their longitudinal section using wirecut. They were grinded and polished before the images were taken.

3. Results and Discussion

Type your paragraphs here. For all formatting structure refer to previous guidelines

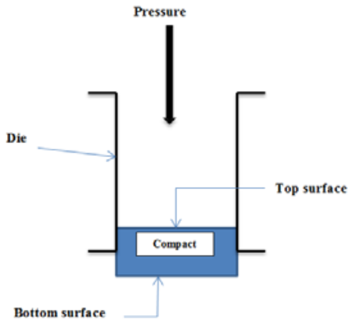

Figure 1. The top and bottom surfaces of a compact

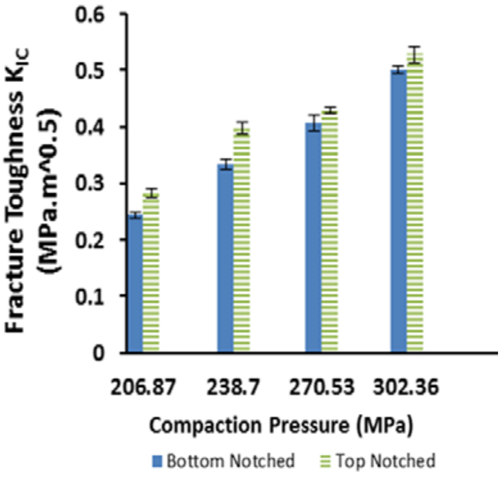

Figure 2.   Variation of fracture toughness with compaction pressure for iron powder compacts notched on different surface

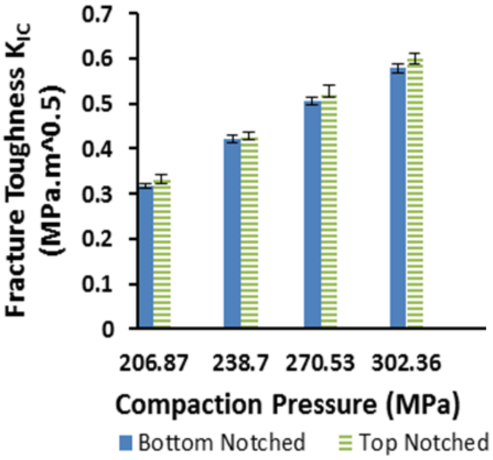

Figure 3.   Variation of fracture toughness with compaction pressure for copper powder compacts notched on different surface

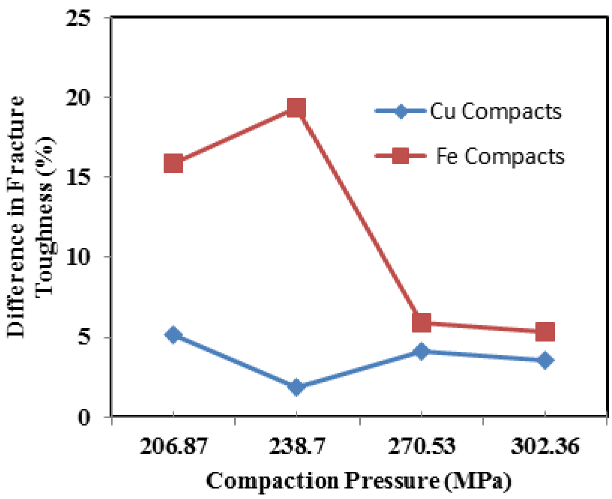

Figure 4.   Percentage difference in fracture toughness at different pressures for iron and copper powders

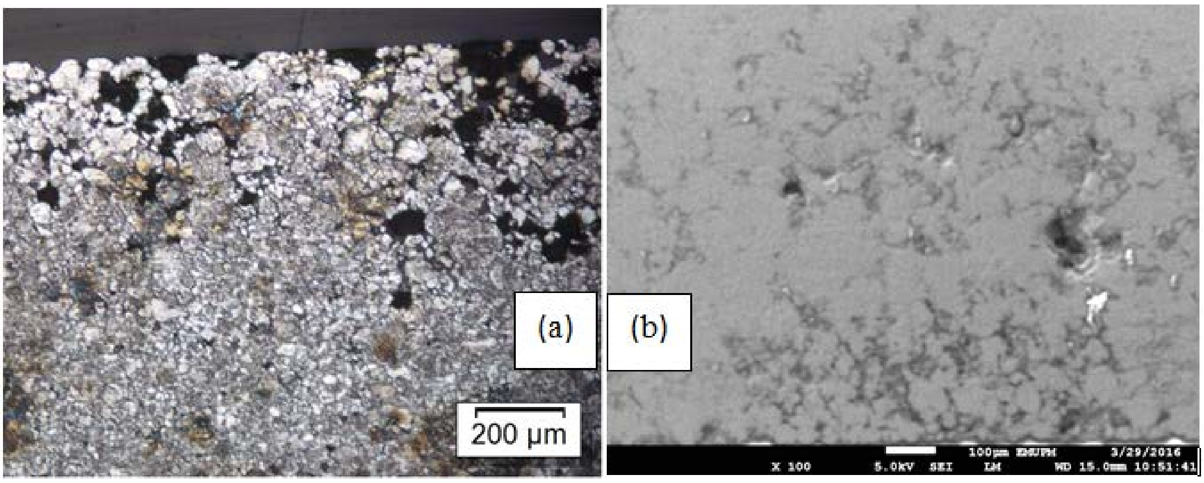

Figure 1. Micrographs of iron powder compact notched on the top surface (a) OM image (b) FeSEM image

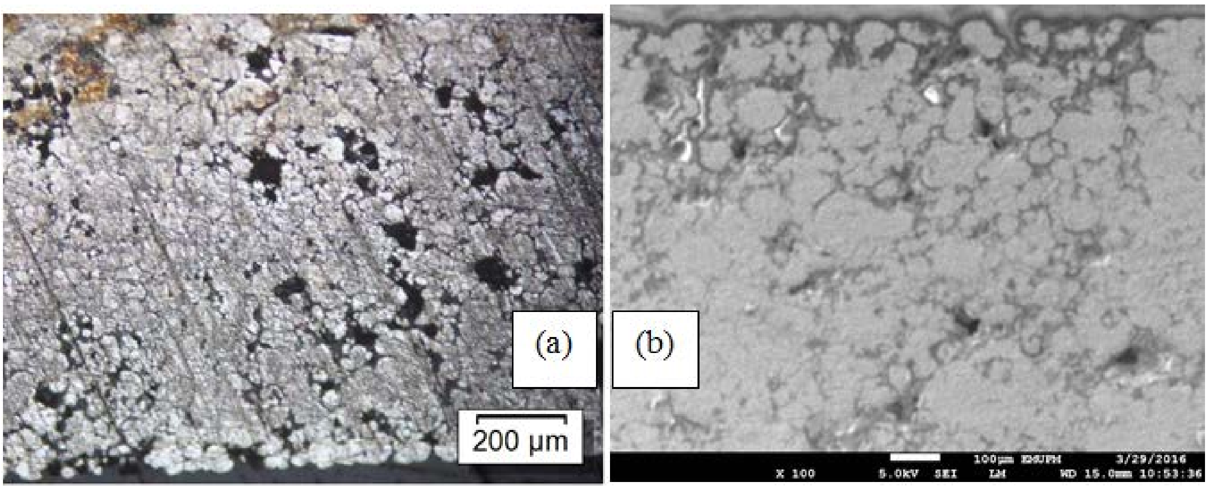

Figure 2. Micrographs of iron powder compact notched on the bottom surface (a) OM image (b) FeSEM image

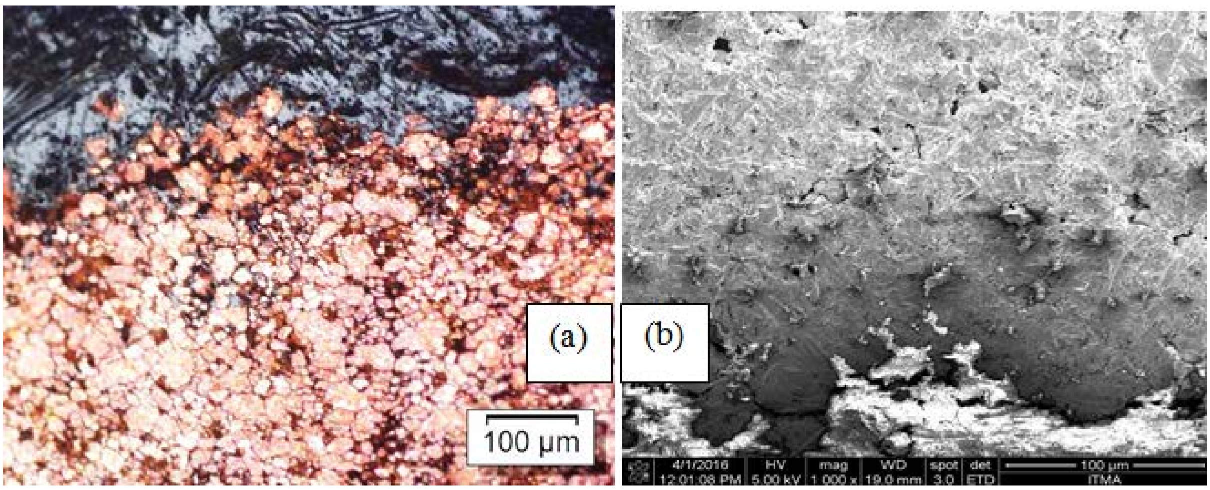

Figure 3. Micrographs of copper powder compact notched on the top surface (a) OM image (b) FeSEM image

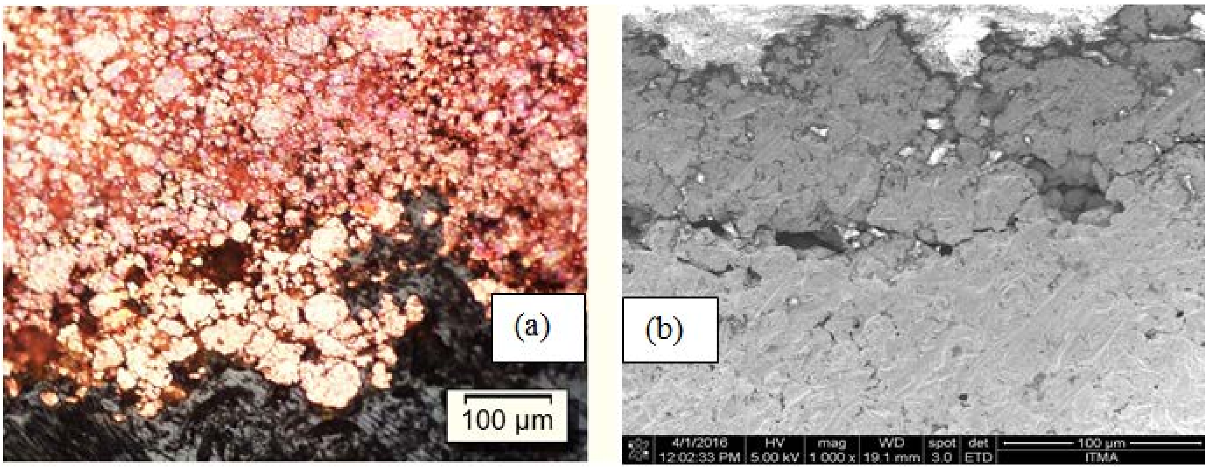

Figure 4. Micrographs of copper powder compact notched on the bottom surface (a) OM image (b) FeSEM image

4. Conclusion

Diametrical compression technique using centrally notched specimens have been used to determine the fracture toughness of rocks(Aliha & Ayatollahi, 2014)(Ayatollahi & Torabi, 2010), ceramics(Lidija, Vera, Krešimir, & Alen, 2007), pharmaceutical tablets(Fell & Newton, 1970), metallic and non-metallic materials(Degnan, Shipway, & Kennedy, 2004). But this is the first study that the surface on which a notch is made is distinguished from the other surface. The two powders studied, iron and copper, are among the most commonly used for the production of PM components, and they both produced compacts of good green strength at all the pressures used. It was obvious that specimens notched on the top surfaces gave higher K_{IC} values. Therefore, it is important for researchers and material characterization experts to always state, among others, the notched surface when reporting the K_{IC} of a powder compact.

Acknowledgements

This project is supported by Universiti Putra Malaysia (GP-IPS/2015/9452300) and Ministry of Higher Education Malaysia (03-01-15-1758FR)

References

Aliha, M. R. M., & Ayatollahi, M. R. (2014). Rock fracture toughness study using cracked chevron notched Brazilian disc specimen under pure modes I and II loading – A statistical approach. *Theoretical and Applied Fracture Mechanics*, *69*, 17–25. doi:10.1016/j.tafmec.2013.11.008

Anand, S. S., & Mohan, B. (2012). Effect of particle size, compaction pressure on density and mechanical properties of elemental 6061Al alloy through powder metallurgical process. *International Journal of Materials Engineering Innovation*, *3*(3/4), 259–268. doi:10.1504/IJMATEI.2012.049265

Ayatollahi, M. R., & Torabi, A. R. (2010). Determination of mode II fracture toughness for U-shaped notches using Brazilian disc specimen. *International Journal of Solids and Structures*, *47*(3-4), 454–465. doi:10.1016/j.ijsolstr.2009.10.012

Degnan, C. C., Kennedy, A. R., & Shipway, P. H. (2004). Fracture toughness measurements of powder metallurgical (P/M) green compacts: A novel method of sample preparation. *Journal of Materials Science*, *39*(7), 2605–2607. doi:10.1023/B:JMSC.0000020039.84002.be

Degnan, C. C., Shipway, P. H., & Kennedy, A. R. (2004). Comparison of the green strength of warm compacted Astaloy CrM and Distaloy AE Densmix* powder compacts. *Materials Science and Technology*, *20*(6), 731–738. doi:10.1179/026708304225017292

Fell, J. T., & Newton, J. M. (1970). Determination of Tablet Strength by the Diametral-Compression Test. *Journal of*

Pharmaceutical Sciences, *59*(5), 688 – 691.

Jonsén, P., Häggblad, H.-Å., & Sommer, K. (2007). Tensile strength and fracture energy of pressed metal powder by diametral compression test. *Powder Technology*, *176*(2-3), 148–155. doi:10.1016/j.powtec.2007.02.030

Lenel, F. V. (1980). *Powder Metallurgy: Principles and Applications*. New Jersey: Metal Powder Industries Federation.

Lidija, C., Vera, R., Krešimir, G., & Alen, M. (2007). Hardness and fracture toughness of alumina ceramic. In *12. Conference on Materials, Processes, Friction and Wear* (pp. 40–45).

Lund, J. (1982). Origins of Green Strength in iron P/M compacts. *International Journal of Powder Metallurgy and Powder Technology*, *18*(2), 117–127.

Norman, B., Alex, R., & Xici, L. (1994). Notching machine and method for mechanical testing specimens. United State: United States Patent.

Procopio, A. T., Zavaliangos, A., & Cunningham, J. C. (2003). Analysis of the diametrical compression test and the applicability to plastically deforming materials. *Journal of Materials Science*, *38*(17), 3629–3639. doi:10.1023/A:1025681432260

Rowell, R. J. (1995). Suggested method for determining mode I fracture toughness using Cracked Chevron Notched Brazilian Disc (CCNBD) specimens. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, *32*(I), 57–64.

Seeling, R. P., & Wulff, J. (1946). The pressing operation in the fabrication of articles by powder metallurgy. *POWDER METALL, UK*, *166*, 492–504.

Varin, R., Zbroniec, L., Czujko, T., & Song, Y.-K. (2001). Fracture toughness of intermetallic compacts consolidated from nanocrystalline powders. *Materials Science and Engineering: A*, *300*(1-2), 1–11. doi:10.1016/S0921-5093(00)01809-8