Laboratory investigation of the anisotropic confinement-dependent brittle-ductile transition of a Utah coal

Bo-Hyun Kim*, Mark K. Larson
Mine Safety Branch, CDC/NIOSH/SMRD, Spokane, WA 99207, USA

Abstract

This paper was developed as part of an effort by the National Institute for Occupational Safety and Health (NIOSH) to identify risk factors associated with bumps in the prevention of fatalities and accidents in highly stressed, bump-prone ground conditions. Changes of failure mechanism with increasing confinement, from extensional-to shear-dominated failure, are widely observed in the rupture of intact specimens at the laboratory scale and in rock masses. In the previous analysis conducted in 2018, both unconfined and triaxial compressive tests were conducted to investigate the strength characteristics of some specimens of a Utah coal, including the spalling limits, the ratio of apparent unconfined compressive strength (AUCS) to unconfined compressive strength (UCS), the damage characteristics, and the post-yield dilatancy. These mechanical characteristics were found to be strongly anisotropic as a function of the orientation of the cleats relative to the loading direction. However, the transition from extensional to shear failure at the given confinements was not clearly identified. In this study, a total of 20 specimens were additionally prepared from the same coal sample used in the previous study and then tested under both unconfined and triaxial compressive conditions. The different confining stresses are used as analogs for different width-to-height (W/H) ratios of pillar strength. Although the W/H ratios of the specimens were not directly considered during testing, the equivalent W/H ratios of a pillar as a function of the confining stresses were estimated using an existing empirical solution. According to this relationship, the W/H at which in-situ pillar behavior would be expected to transition from brittle to ductile is identified.

Keywords

Bump-prone ground conditions; A Utah coal; Anisotropic; Equivalent W/H ratios of a pillar

1. Introduction

This paper was developed as part of an effort by the National Institute for Occupational Safety and Health (NIOSH) to identify risk factors associated with bumps in the prevention
of fatalities and accidents in highly stressed, bump-prone ground conditions. High stress environments bring many technical challenges in deep underground mining. With the continued increase of depth of mining, a number of new challenges have been encountered in underground excavations [1]. Dynamic failure events (also called “bumps” or “bursts”) have been documented for well over 100 years within the American underground coal mining industry. The assessment of such dynamic failure hazards in coal mines depends on fundamental knowledge of coal mechanical behavior. A robust characterization of the confinement-dependent mechanical behavior of coal is of importance in order to mitigate the hazards potentially threatening mine workers [2, 3].

Given that coal is expected to fail in a brittle manner under most practical mining conditions, behavioral features associated with its relatively low tensile strength, such as the transition from extensional to shear failure as a function of confining stress, have to be considered and reflected in the adopted failure criteria. In particular, rock failure in tension takes place at low confinement around excavations due to brittle cracking at the grain scale [4]. The prospect of tensile-fracture-dominated extensional failure diminishes as the confinement increases away from the excavation boundary. Therefore, it is anticipated that the transition from extensional to shear failure mechanism occurs as the confinement level changes and the conditions for tensile failure are prevented or strongly diminished, such as is expected in the core of a coal pillar [1]. The horizontal stresses inside a pillar increase with an increase in the width-to-height (W/H) ratio [5]. Accordingly, the effect of confining stress on laboratory compressive strength can be used as an analog for the effect of W/H ratio on pillar strength [6].

The exact nature of failure mechanism transitions is likely to be influenced by the highly anisotropic characteristics of coal seams associated with the geologic structure and the mining-induced spatial redistribution of stress in coal pillars [2]. Kim et al. investigated the strength, brittleness, and dilation anisotropy of a Utah coal using both unconfined and triaxial compressive tests by considering four orientations between the cleat and the axial loading direction in the coal specimen [2]. From the investigation, the mechanical characteristics were found to be highly anisotropic and controlled by the orientation of the cleats relative to the loading direction. However, the transition from extensional to shear failure at the given confinements was not clearly observed as anticipated based on the s-shaped brittle-failure criterion [2]. This criterion has clear divisions among extensional failure, transitional failure, and shear failure, and it was our objective to use this criterion to model the coal strength.

In order to study the strength characteristics of coal under high confinement and, hence, provide insights for pillar stability and design, a second laboratory testing campaign was conducted to examine the effect of confinement on the transition of the failure mode of the Utah coal. A total of 20 additional specimens were recovered from the Utah coal sample that was used in the previous study [2]. In that study, all confining stresses were no larger than 50% of the mean unconfined compressive strength. For the present study, a higher magnitude of confining stress than the originally determined mean unconfined compressive strength (UCS) was applied to the specimens. Because in the previous study the included angle (the angle between the cleat and the loading direction) was found to be an important
variable affecting the coal strength, in this study the two most contrasting cases of the included angle, $0^\degree$ and $30^\degree$, were used to evaluate the mechanical behavior of the coal under high confinement [2]. The confining stress as a ratio of the mean UCS was increased in successive tests until a relatively ductile post-peak stress–strain behavior stage was achieved. The maximum applied confining stress was equivalent to 5 times (for $0^\degree$ of the included angle) and 4 times (for $30^\degree$ of the included angle) the mean UCS values for the two cases.

2. Laboratory tests of the coal specimens considering high confinements

For this study, 14 triaxial tests and 6 UCS tests were performed at Montana Tech in Butte, MT. The purpose of the triaxial tests was to examine the characteristics of brittle/ductile transition in coal, and the UCS tests were used to confirm consistency and comparability with the results from the previous study conducted by Kim et al. [2]. A total of 20 cylindrical specimens were cored from the same Utah coal boulders from which the cores in the previous study were obtained and then tested by Kim et al. [2]. The coal boulders were collected from the Tank Seam of the Blackhawk formation, Wasatch Plateau, Central Utah. Because the influence of the included angle between the cleats and the loading direction was already studied in detail by Kim et al., coring was conducted so that only the two most contrasting cases of the included angle with respect to mechanical behavior ($0^\degree$ and $30^\degree$) were obtained and prepared for the tests [2]. Using the same procedures adopted by Kim et al., all specimens in this study were cored to an approximate diameter of 44 mm and cut to be within the ASTM (D 4543-08) recommended range of 2.0 to 2.5 length-to-diameter ratio [2]. The ends of the specimens were ground on a surface grinder to be within the ASTM (D 4543-08) flatness tolerance of 0.025 mm. Specimen end parallelism and perpendicularity tolerances were verified using a parallelism testing gauge. The tests were performed using a TerraTek Model FX-S-33090 closed loop digital servo-controlled load frame. The testing system, shown in Fig. 1, consists of a TerraTek 113.4 tonnes force load cell to measure force, two impervious endcaps, two Schaevitz MHR 500 LVDTs to measure axial displacement, a TerraTek radial cantilever transducer to measure lateral strain, and spherical seats to minimize the risk of non-uniform loading of the specimen. The 14 triaxial samples were jacketed with 0.5-mm-thick Dunbar-1635F flexible 2:1 Polyolefin to prevent the confining fluid from penetrating the sample. The six UCS samples were tested without jackets. Both the UCS and the triaxial test procedures followed the ASTM suggested method (D7012). Both the triaxial and UCS test procedures were run under axial strain rate control with specimens axially loaded at a strain rate of $2.54\times10^{-5}$ mm/mm/s.

3. Analysis of the test

3.1. Observation of coal specimen failure

The photographs obtained after the new suite of tests show that all the specimens failed mainly in shear when the confining stress was equal to or greater than 100% of the mean UCS for the included angle of $0^\degree$ and 200% of the mean UCS for the included angle of $30^\degree$ (Figs. 1 and 2). For the $0^\degree$ included angle specimens, at 11 MPa confinement (Fig. 1a), extensional-axial cracking was observed. With increasing confinement, brittle shear failure was observed. Fig. 1f shows a shear failure surface typically associated with semi-ductile
failure at the highest confining stress (110 MPa), in that strain localization is still occurring (cracks visible), but the localization is not well defined or limited to a single shear plane. In comparison to a more naturally ductile rock, we can observe that this type of failure pattern is comparable to what has been observed from testing under 15 MPa confinement for Indiana Limestone [7].

3.2. Effect of confinement on post-peak (brittle/non-brittle) behavior in the coal specimens

This section discusses the results of the laboratory tests in order to investigate the post-peak behavior as a function of the critical included angles in the coal specimens. It is very common for triaxial tests on coal specimens to show evidence of shear failure at all confining stress levels, including under unconfined conditions.

Cook, Cook and Hojem noted that a laboratory test specimen may crush violently or benignly, depending on the stiffness of the testing system relative to the post-failure stiffness of the specimen [8,9]. In the transitional failure regime, episodes of brittle response from microcracking can cause small drops in load. A test system with insufficiently high stiffness might then apply dynamic forces, which drive more fracturing than would a very stiff testing system. For this reason, a very stiff testing machine was employed for this study. The stress-versus-strain curves obtained (Fig. 3) are considered reliable because any parts of the curves that were not densely represented by points (i.e. where control was lost due to brittle failure at peak stress, or during the unloading segments after the completion of the test) have been removed. It should be noted that very large amounts of axial strain were applied in order to reach peak strength, with the large strains accommodated by localized displacements along pre-existing discontinuities, resulting in the localized shear failures observed even in specimens subjected to confining stresses well above the UCS and displaying semi-ductile stress–strain behavior. The localized shear failures observed are in agreement with those observed in the previous study [2].

Fig. 3 shows the stress–strain curves of the triaxial compressive tests on the 14 coal specimens conducted with different confining stresses. Fig. 3a presents the results of tests on the specimens with an included angle of 0°. Fig. 3b illustrates the test results on the specimens with an included angle of 30°. The confinements of 11 MPa for 0° and 4 MPa for 30° are obtained from the study performed by Kim et al. [2]. The confining stresses of 22 and 16 MPa are equivalent to the mean UCS for the included angles of 0° and 30°, respectively. For the specimens having an included angle of 0° as shown in Fig. 3a, the results show that following attainment of peak strength, the stress–strain curves show strain-weakening (semi-ductile behavior) when the applied confining stress was 66 MPa. This pressure is as high as 3 times the mean UCS. For the specimens having an included angle of 30° as shown in Fig. 3b, the results show a similar semi-ductile residual stress–strain curve when the applied confining stress was 40 MPa. This pressure is as high as 2.5 times the mean UCS. Even at the highest confining stresses in both cases, the stress–strain data indicate that perfectly plastic behavior was not attained. This is consistent with the fact that for all tests, observed shear failure was localized rather than diffuse.
4. **Prediction of the brittle/ductile transition in coal pillars as a function of W/H ratio**

Confinement in a pillar is greatly affected by the width-to-height (W/H) ratio of the pillar. Although not considered as a tested parameter in this study, the W/H ratio of samples has been shown to drastically affect residual strength levels, even more so than it affects the peak strength, as shown in Fig. 4 [10,11]. At low W/H ratios of 0.5 or 1.0, a rock sample may be extremely brittle, losing all strength immediately after attainment of peak strength. With increasing W/H ratio, the stress–strain curves of uniaxial tests begin to show residual strength, followed by ductile and strain-hardening behavior. The degree of hardening is expected to increase with increasing W/H ratio [10]. Small W/H ratios have been associated with several massive pillar collapses that occurred in the United States [12].

Confining stress also has a similar effect in changing a rock sample’s behavior that might be brittle under unconfined conditions to ductile or even strain hardening [8,13–17].

In the case of South African coal mining, the typical pillar W/H ratio is from 3 to 4 with an average 3 m-thick mined seam at a depth of 250 m below the surface. Extensional failure has been observed for mine pillars in South Africa with W/H ratios up to at least 4 [18]. The semi-ductile failure mode can occur only in pillars with sufficiently large W/H ratios, which allows high lateral confinement stresses to be generated within the fractured pillar. While the load-bearing capacity of brittle pillars is dominated by the cohesive strength of the material, pseudo-ductile pillars obtain their seemingly unlimited load-bearing capacity from the frictional ductile resistance of fractured material [18].

Esterhuizen et al. calibrated numerical coal pillar models against the empirical linear strength formula and measured stress profiles for in-situ pillar ribs [19]. The extrapolation of the models to greater W/H ratios predicts that the brittle-ductile transition occurs in pillars having a W/H ratio of approximately 8.

Moomivand and Vutukuri reported that the coal specimens with a W/H ratio ranging from 0.25 to 2.0 had brittle behavior and failed completely after yielding, but differences in the yield strength and ultimate strength inside the specimens were increased by an increase in W/H ratio from 2 to 3.5 [6]. The core of pillar specimens behaved in a ductile fashion when the W/H ratio was greater than 3.5. As the W/H ratio was greater than or equal to 4, the axial load was increased by more than a factor of two after yielding at the periphery, and the insides of a high percentage of the specimens which had ductile behavior were intact[6].

We presumed that the range of the confining stress considered in the study was performed by Kim et al., and that this study could be substituted by a set of equivalent W/H ratios of the coal specimens [2]. If there is a meaningful correlation between the confining stress and the W/H ratios, the result will help us better understand the brittle-ductile transition for in-situ pillars.

The effect of an increase in the W/H ratio on pillar compressive strength, including the increase in lateral stresses in the pillar because of an increase in end constraints, is
comparable with the effect of confining stress on a specimen’s axial compressive strength. Using regression formulas, the effect of confining stress on peak strength can be compared to the effect of the W/H of pillar peak strength, meaning an equivalent W/H value can be derived for each confining stress. It has previously been demonstrated that the relationship between the compressive strength and the W/H ratio of square prisms when 0.3 ≤ W/H ratio ≤ 5 is comparable to the relationship between axial compressive stress at failure and confining stress in triaxial tests, but the exponents of the W/H ratio and confining stress are not equal [6]. In this section, the exponents of the W/H ratio and the confining stress showing the relationship between the values are estimated and discussed.

Holland performed an extensive laboratory testing program in which coal specimens from different coal seams in West Virginia, USA, were tested at W/H ratios between 1 and 12 [20]. Holland described the results to be very erratic in general but demonstrated that a linear or regressive increase in specimen strength up to a W/H ratio of 8 fitted the average data well [20]. The tested coal pillar strength was back-calculated by Mathey and Van der Merwe using the various empirical strength formulae proposed by Bieniawski, Van Heerden, and Wagner [18,21–24]. The data fit well to an equation where the strength normalized to the UCS was equal to a constant times the square root of W/H as shown in Eq. (1).

$$\frac{\sigma_p}{UCS_{\text{mean}}} = k\sqrt{\frac{W}{H}}$$ (1)

where $$\sigma_p$$ is the pillar strength; $$UCS_{\text{mean}}$$ the average unconfined compressive strength; and $$k$$ a constant.

Fig. 5 shows the results of all the testing data fitted using the square-root equations of coal pillar strength. It is evident that the data can be represented adequately well ($$r^2 = 0.90–0.94$$) by the square-root equation for coal pillar strength.

We now adopt a methodology proposed by Moomivand and Vutukuri showing the relationship between the ratio of compressive strength and W/H ratio of coal specimens to calculate equivalent exponents of confining stress and W/H ratio in the equation[6].

Moomivand and Vutukuri utilized the following equations to estimate the exponents of equivalent confining stress that would produce the measured strength in a triaxial compressive test and W/H ratio [6].

$$\frac{\sigma_1}{UCS} = 1 + b'(\frac{\sigma_3}{UCS})^\beta$$ (2)

$$\frac{\sigma_c}{UCS} = A' + B'\left(\frac{W}{H}\right)^a \rightarrow \frac{W}{H} = \left(\frac{\sigma_c/UCS - A'}{B'}\right)^{\frac{1}{a}}$$ (3)

where $$\sigma_1$$ and $$\sigma_3$$ are the principal stresses; UCS the unconfined compressive strength; $$b'$$ and $$\beta$$ constants; $$\sigma_c$$ the compressive strength of pillar specimens; UCS the unconfined compressive strength; and $$A'$$, $$B'$$ and $$a$$ constants.
Using these equations, all the testing data including the results studied by Kim et al. were analyzed to estimate the exponents of confining stress and W/H ratio [2]. The results are shown in Figs. 6 and 7.

Mathey and Van der Merwe reported that the evidence presented from field experience, laboratory tests, and numerical and analytical models corroborates the conclusion that a progressive increase in coal pillar strength for W/H ratios greater than 5 does not exist [18]. Moomivand and Vutukuri showed that the periphery of a pillar behaves in a brittle fashion for any value of width-to-height ratio and the core of a pillar behaves in a ductile fashion for pillars with W/H greater than 3.5 [6].

From the results, we learn a critical value of W/H ratio for the Utah coal at which we would expect a transition from brittle to semi-ductile behavior. As shown in Tables 1 and 2, the ratio of the confining stress to the mean UCS in this study is approximately 4 (confining stress of 88 MPa for 0° and 64 MPa for 30°), and the critical equivalent W/H ratio is around 4.

5. Conclusions

In this study, a laboratory investigation using both unconfined and triaxial compressive tests that examine the strength, brittleness, and dilation anisotropy of a Utah coal is presented. Two orientations between the cleat set and axial loading direction in the coal specimen were considered as a testing parameter.

Through analysis of post-testing photographs, post-peak stress–strain data, and pre-peak volumetric attributes (crack volumetric strain reversal and dilation angle mobilization), it was determined that for the 0° included angle specimens, the brittle-ductile transition initiates around $\sigma_3 = 88$ MPa; for the 30° included angle specimens, the brittle-ductile transition initiates around $\sigma_3 = 40–64$ MPa. These values are both much higher than would be expected based on conventional models for the brittle-ductile transition in rock, and this was attributed to the anomalously high brittleness-to-strength ratio of the rock considered in this study.

Although the W/H ratios of the specimens were not directly considered during testing, the equivalent W/H ratios of a pillar as a function of the confining stresses were estimated using an existing empirical solution. According to this relationship, the W/H at which in-situ pillar behavior would be expected to transition from brittle to ductile is identified. A previously proposed relationship was used to convert the confining stresses considered in the laboratory tests into equivalent pillar W/H ratios. Based on this calculation, it was determined that in the coal considered in this study, pillars would transition from brittle to ductile behavior at W/H ratios of approximately 4 in both cases of the included angles for the Utah coal specimens. The critical value of W/H ratio for the Utah coal may need to be investigated further by considering an in-situ condition for future work.

Acknowledgement

The authors would like to thanks to Steve Berry at Montana Tech for his working on the lab testing.
References

[1]. Kaiser PK, Kim B, Bewick RP, Valley B. Rock mass strength at depth and implications for pillar design. Min Technol 2011;120:170–9.

[2]. Kim BH, Walton G, Larson MK, Berry S. Experimental study on the confinement-dependent characteristics of a Utah coal considering the anisotropy by cleats. Int J Rock Mech Min Sci 2018;105:182–91.

[3]. Kim BH, Larson MK, Lawson HE. Applying robust design to study the effects of stratigraphic characteristics on brittle failure and bump potential in a coal mine. Int J Min Sci Technol 2018;28:137–44. [PubMed: 29416902]

[4]. Diederichs MS. Mechanistic interpretation and practical application of damage and spalling prediction criteria for deep tunnelling. Can Geotech J 2007;44:1082–116.

[5]. Bieniawski ZT. The effect of specimen size on compressive strength of coal. Int J Rock Mech Min Sci 1968;5:325–35.

[6]. Moomivand H, Vutukuri VS. Effect of geometry on the compressive strength of pillars In: Mining Science and Technology: Proceedings of the ’96 International Symposium on Mining Science and Technology. Xuzhou, Jiangsu, China: October 16–18, 1996, Rotterdam: Balkema A. A., 1996, pp. 715–20.

[7]. Walton G, Hedayat A, Kim E, Labrie D. Post-yield strength and dilatancy evolution across the brittle–ductile transition in Indiana limestone. Rock Mech Rock Eng 2017;50:1691–710.

[8]. Cook NGW. The failure of rock. Int J Rock Mech Min Sci 1965;2:389–403.

[9]. Cook NGW, Hojem JPM. A rigid 50-ton compression and tension testing machine. J South African Inst Mech Eng 1966;1:89–92.

[10]. Das MN. Influence of width/height ratio on post-failure behaviour of coal. International Journal of Mining and Geological Engineering 1986;4:79–87.

[11]. Özbay MU. The stability and design of yield pillars located at shallow and moderate depths. J S Afr Inst Min Metall 1989;89:73–9.

[12]. Chase FE, Zipf J, Karl R, Mark C. In: The massive collapse of coal pillars—case histories from the United States. Morgantown, WV: West Virginia University; 1994; p. 69–80.

[13]. Wawersik WR, Fairhurst C. A study of brittle rock fracture in laboratory compression experiments. Int J Rock Mech Min Sci Geomech Abstr 1970;7:561–75.

[14]. Price AM. The effects of confining pressure on the post-yield deformation characteristics of rocks (Ph.D. thesis). University of Newcastle upon Tyne; 1979.

[15]. Hakami MH. Post-failure behaviour of brittle rock. Luleå University of Technology; 1988. p. 150 (Ph.D. thesis).

[16]. Kumar R, Sharma KG, Varadarajan A. Post-peak response of some metamorphic rocks of India under high confining pressures. Int J Rock Mech Min Sci 2010;47:1357–62.

[17]. Bawden WF. Thoughts on quantitative field scale characterization of post-failure rock mass conditions and their influence on underground mine design In: Proceedings: 44th U.S. Rock Mechanics Symposium and 5th U.S./Canada Rock Mechanics Symposium. Salt Lake City, UT: June 27–30, 2010, Alexandria, VA: American Rock Mechanics Association, 2010, 18 pp.

[18]. Mathey M, Van der Merwe JN. Critique of the South African squat coal pillar strength formula. J S Afr Inst Min Metall 2016;116:291–9.

[19]. Esterhuizen E, Mark C, Murphy MM. In: Numerical model calibration for simulating coal pillars, gob and overburden response. Morgantown, WV: West Virginia University; 2010. p. 46–57.

[20]. Holland CT. Physical properties of coal and associated rock as related to the causes of bumps in coal mines. Technical Publication No. 1406, New York: American Institute of Mining and Metallurgical Engineers 1942, 1–17 pp.

[21]. Bieniawski ZT. In situ strength and deformation characteristics of coal. Eng Geol 1968;2:325–40.

[22]. Bieniawski ZT. The compressive strength of hard rock. Tydskrif vir Naturwetenskappe 1968;8:163–82.
[23]. Van Heerden WL. In situ complete stress-strain characteristics of large coal specimens. J S Afr Inst Min Metall 1975; 75: pp. 207–17, e:\Electronic papers \Van Heerden 1975 In Situ Complete Stress-Strain Characteristics of Large Coal Specimens.pdf.

[24]. Wagner H. Determination of the complete load-deformation characteristics of coal pillars In: Advances in Rock Mechanics: Reports of Current Research: Proceedings of the Third Congress of the International Society for Rock Mechanics. Denver, CO: September 1–3, 1974, Washington, D.C.: National Academy of Sciences, 1974, pp. 1076–81.
Fig. 1.
Examples of failed coal specimens with 0° included angle (mean UCS 22 MPa) after triaxial compressive strength testing.
Fig. 2.
Examples of failed coal specimens with $30^\circ$ included angle (mean UCS 16 MPa) after triaxial compressive strength testing.
Fig. 3.
Complete axial stress–strain curves obtained in triaxial compression tests on the coal at various confining stresses.
Fig. 4.
Plots of experimental results of stress versus strain on coal according to various W/H ratios.
Fig. 5.
Results of the triaxial compressive tests fitted with the various different empirical methods.
Fig. 6.
Results of the triaxial compressive tests fitted with Moomivand & Vutukuri’s approach on the geometry effect of pillar [6].
Fig. 7.
Results of the triaxial compressive tests fitted with the Moomivand & Vutukuri’s approach on the confining effect of pillar [6].
| W/H | σ₃ (MPa) | σ₁ (MPa) | σ₃/UCS | σ₁/UCS | σ₀/UCS |
|-----|----------|----------|--------|--------|--------|
| 22  | 104.3    | 1.0      | 5.1    | 1.0    |        |
| 44  | 143.4    | 2.0      | 6.5    | 1.7    | 1.0    |
| 66  | 174.4    | 3.0      | 8.6    | 3.1    | 1.7    |
| 66  | 174.4    | 3.0      | 8.3    | 2.8    |        |
| 66  | 174.4    | 3.0      | 8.2    | 2.8    | 1.7    |
| 88  | 201.0    | 4.0      | 9.7    | 3.8    | 1.7    |
| 110 | 224.9    | 5.0      | 11.2   | 5.1    | 1.7    |
Table 2

Relationship between ratio of strength and W/H ratio of 30° sample.

| W/H | $\sigma_3$ (MPa) | $\sigma_1$ (MPa) | $\sigma_3$/UCS | $\sigma_1$/UCS | W/H |
|-----|------------------|------------------|----------------|----------------|-----|
| 16  | 80.1             | 1.1              | 6.0            | 1.3            |     |
| 32  | 114.9            | 2.3              | 8.5            | 2.4            |     |
| 40  | 129.7            | 2.9              | 9.3            | 2.8            |     |
| 40  | 129.7            | 2.9              | 9.7            | 2.9            |     |
| 40  | 129.7            | 2.9              | 9.7            | 2.9            |     |
| 64  | 168.1            | 4.6              | 12.2           | 4.3            |     |