优秀博士学位论文摘要

煤矿巷道树脂锚固体力学行为及锚杆杆体承载特性研究

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摘　要: 目前锚杆(索)支护技术是我国地下煤矿开采中普遍采用的一种主动控制巷道围岩稳定的支护技术。但由于锚杆支护加固对象的复杂性,至今锚杆支护原理还没有一个统一全面的认识,对于复杂条件下锚杆的锚固机理、与围岩相互作用关系、应力分布规律及锚杆杆体承载特性等问题需要更深入的研究。论文采用理论分析、数值模拟、现场实测、实验室试验和工程实践相结合的综合研究手段,围绕树脂锚固体力学行为及锚杆杆体承载特性展开研究。论文研究的主要工作如下:

(1) 总结分析了树脂锚固体 4 类主要失效类型,着重分析了黏结失效类型中树脂锚固体空洞锚固失效和长时蠕变失效的两种形式。建立了空洞树脂锚固体拉拔状态下的力学模型,推导并求出了空洞树脂锚固体拉拔状态下沿锚固方向上杆体内拉应力分布的理论公式; 同时建立了考虑锚固层黏弹特性树脂锚固体拉拔状态下的长时蠕变力学模型,推导并求出了与时间有关的杆体拉应力和锚固层-杆体界面剪应力分布公式,并求解了恒力长时作用下的树脂锚固体杆体外端点位移的近似公式,同时得到了锚固体产生破坏的极限拉拔力。

(2) 通过实验室力学试验,获得了围岩、锚杆等力学参数。基于 ABAQUS 数值模拟软件,验证了两种锚固体理论力学模型,研究了两种模型中杆体应力沿锚固方向上的分布规律,揭示了拉拔过程中锚固体内应力和位移的演化过程; 着重阐述了长时蠕变模型杆体应力传递的 3 个阶段,分析了杆体的极限抗拉拔力与时间的关系。同时,分析了锚杆直径、锚固层厚度、钻孔直径、围岩强度等参数对树脂锚固体杆体拉拔状态下的力学特性影响。

(3) 采用预拉力锚固系统锚固作用综合实验台,研究了不同预拉力下锚杆杆体应力和弯矩的分布特征及其变化速率; 通过测力锚杆井下拉拔试验,揭示了预拉力与锚杆杆体外端点位移的相互关系及不同预拉力下锚杆杆体轴力分布及承载特征,同时基于测得的锚杆杆体应力分布曲线,借助第三章研究结果,准确推测了巷道顶板的完整性; 初步判定预拉力锚杆实际工作状态下杆体承载受力主要集中在外锚固段中性点附近,对限制巷道围岩变形起主要作用的是中性点附近杆体-锚固层-围岩 3 者之间的黏结关系,同时杆体内弯矩的存在说明杆体截面处于非均匀受力状。

(4) 在分析现有煤矿巷道围岩监测手段的不足和光纤光栅传感技术优越性的基础上,初步提出并建立了一套基于现代光纤传感技术的煤矿巷道围岩动态实时在线监测系统; 并采用该系统对煤矿巷道锚杆杆体受力及演化进行了实测,监测结果表明树脂锚杆的杆体应力分布呈非均匀分布且波动变化,杆体内存在大量弯矩。

(5) 最后基于理论研究结果提出了确保锚杆支护效果的几个基本原则,并应用于淮南矿区顾桥矿 1115(1) 工作面轨道巷及朱集煤矿 1111(1) 工作面轨道巷的工程实践,应用结果表明遵循该原则采用的预拉力高强锚杆强化支护技术可以充分调动围岩的自稳能力优化围岩的力学参数,有效控制巷道围岩变形,满足矿井安全生产要求; 同时采用煤矿巷道围岩动态实时在线监测系统成功揭示了 1111(1) 工作面轨道沿空留巷期间的矿压显现规律,并与传统矿压观测结果进行了对比,两者基本一致,初步显示了该系统的可靠性和应用前景。

关键词: 树脂锚固体; 力学行为; 应力分布; 锚固段; 承载特性; 动态实时监测; 预拉力高强锚杆

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Study on mechanical bebavior of epoxy bonded bolt system and bolt bearing characteristic in coal mine roadway

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Abstract: Bolt or cable supporting technology which is active supporting method to control the surrounding rock stability has been widely applied in underground coal mining in China. Based on the complexity of surrounding rock, principles of bolt supporting have not yet common and completely understood, the bolt supporting need more study on the anchorage mechanism, interactive relationship with the surrounding rock, stress distribution along the embedded direction, bolt bearing characteristic and etc. This study took epoxy boned bolt system and bolt supported in coal mine roadway as research back ground, applied theoretical analysis, numerical simulation, field measurement, laboratory test and engineering practice to explore the mechanical behavior of epoxy bonded bolt system and bolt bearing characteristic. The following findings were made:

(1) Four main failure types of epoxy bolt supporting were analyzed and summaried, and imperfectly epoxy bonded failure and long-term creep failure of epoxy bonded bolt system that belong to adhensive failure type were emphatically analyzed. A theoretical model of epoxy bonded bolt system with an imperfect bonding adhesive layer was proposed, based on the this model, the formulas of axial stress in the blot and the shear stress at the bolt-epoxy interface along the embedded direction have been obtained and shown as a piecewise function. Simultaneously, an analytical model of epoxy bonded bolt system considering the visco-elastic effect of the adhesive layer was developed, based on the proposed model, the time dependent formulas of tensile stress and shear stress at the bolt and epoxy interface along the anchor's direction have been obtained. The closed form equation of the long-term load end displacement was derived, additionally, the time dependent of initial debonding load Pini.

(2) Mechanical parameters of the surrounding rock, bolt, etc. were obtained through laboratory mechanical tests. Two suggested models were compared with the FEM simulation in ABAQUS, then the distribution of bolt stress along the longitude direction of bolt in both models were studied, and the evolution process of stress and displacement in bolt system were also presented. Subsequently, parametric study of the constituent parameters of the epoxy bonded bolt system, such as bolt diameter, epoxy layer thickness, etc. were conducted to demonstrate their effects on the the epoxy bonded bolt system.

(3) Bolt performance comprehensive experiment bar for pre-stress bolt system and underground bolt pull-out tests were used to study the distribution and bearing behavior of epoxy bonded bolt system with different pre-stress, the relationship between pre-stress and displacement of bolt endpoint was alos carried out. The research results were preliminary indicated that the bearing stress in bolt under its working condition was complicated and changeable, and bearing stress concentrated around bolt neutral point.

(4) Based on analysis of shortage of present roadway surrounding rock monitoring methods and excellence of FBG sensing technology, a dynamic real-time monitoring system for roadway surrounding rock in coal mine was proposed and successly used to monitor the distribution and evolution of stress in bolt in roadway in coal mine.

(5) Finally, several principles to ensure bolt supporting effect were proposed based on the above results and successfully appied in track transportation gateways of 1115(1) working face of Guqiao coalmine and 1111(1) working face of Zhuji coalmine, Huainan mining group. Simultaneously, track transportation gateway in 1111(1) working face of Zhuji coalmine in Huainan mining group was took as engineering background, the real-time on-line monitoring system for roadway surrounding rock activity in coal mine was successfully applied to monitor the ground pressure during its gob-side entry retaining.

Key words: epoxy bonded bolt system; mechanical behavior; stress distribution; anchorage part; bearing characteristic; dynamical real-time monitor; pre-stress high strength bolt